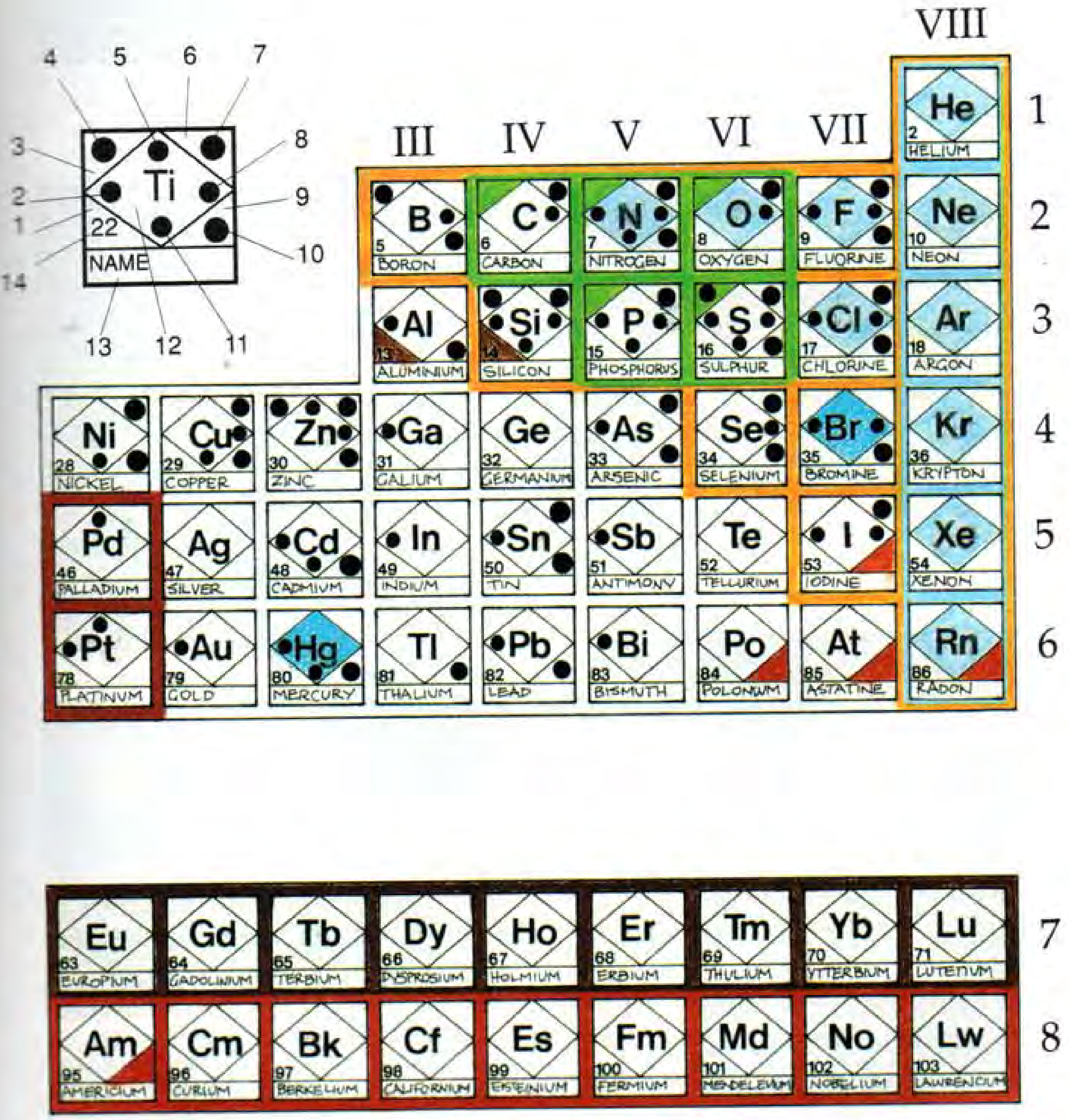
	BORDERS
Green	Hydrocarbons, amino acids (plant and animal tissue) C, H, O, N, S, P.
Yellow	Non-metals.
Dark Blue	Alkali metals.
Light Blue	Inert gases.
Crimson	Major catalysts.
Brown	Rare earths.
Orange	Radioactives.



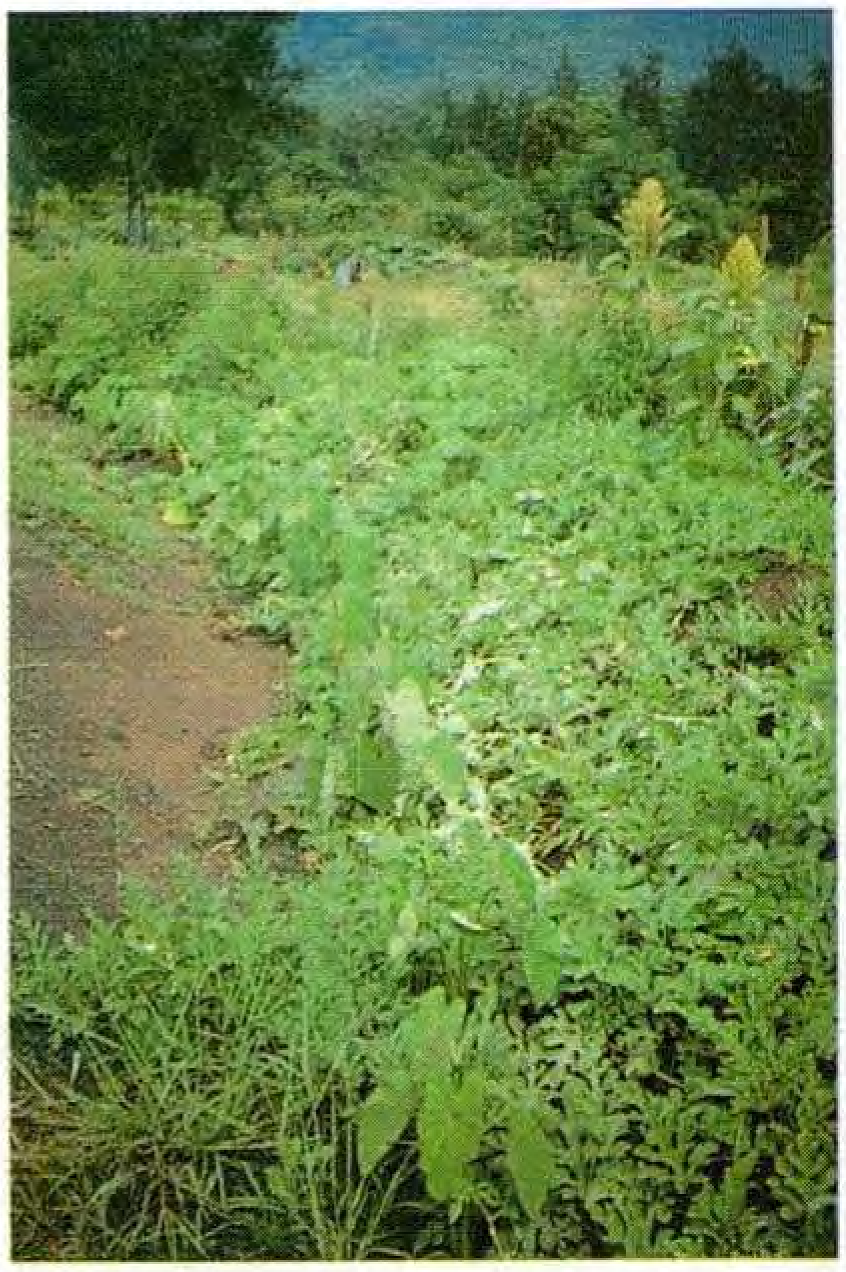
14. SWALES

66. KOONIBBA, SA, AUSTRALIA.
A swale under construction using a side–casting grader in the drylands of central southern Australia.

67. PUMPENBIL, NSW, AUSTRALIA.
Swale under construction.

69. VILLAGE HOMES, DAVIS, CA, USA.
Michael Corbett, designer/developer. New swale area being planted.

68.
Swale in Number **67** six months later with watermelon, sorghum, corn, cucurbits on the bank, and taro in the base.



70. VILLAGE HOMES, DAVIS, CA, USA.
Another swale, heavily shaded by trees which are nourished by the swale soakage. ANDREW JEEVES surveys the lush vegetation growing in what would otherwise be a desert.

71. VILLAGE HOMES, DAVIS, CA, USA.
A gravel–based swale collects water from a suburban road. Because of extensive swaling Village Homes sits on its own deepening, soil–stored, water resevoir in a surrounding desert.

15. DRYLANDS
Building

72. CANYON DE CHELLY, USA.
Mud houses cluster like swallow's nests in a notch at the scarp base of the canyon. Navajo fields and cottonwoods occupy the canyon floor.

73. TAFIRA ALTA, CANARY ISLANDS.
The facade of cave houses is all that reveals the dwelling; excavated in soft tufa (volcanic ash). The rooms need good ventilation to reduce radon levels.

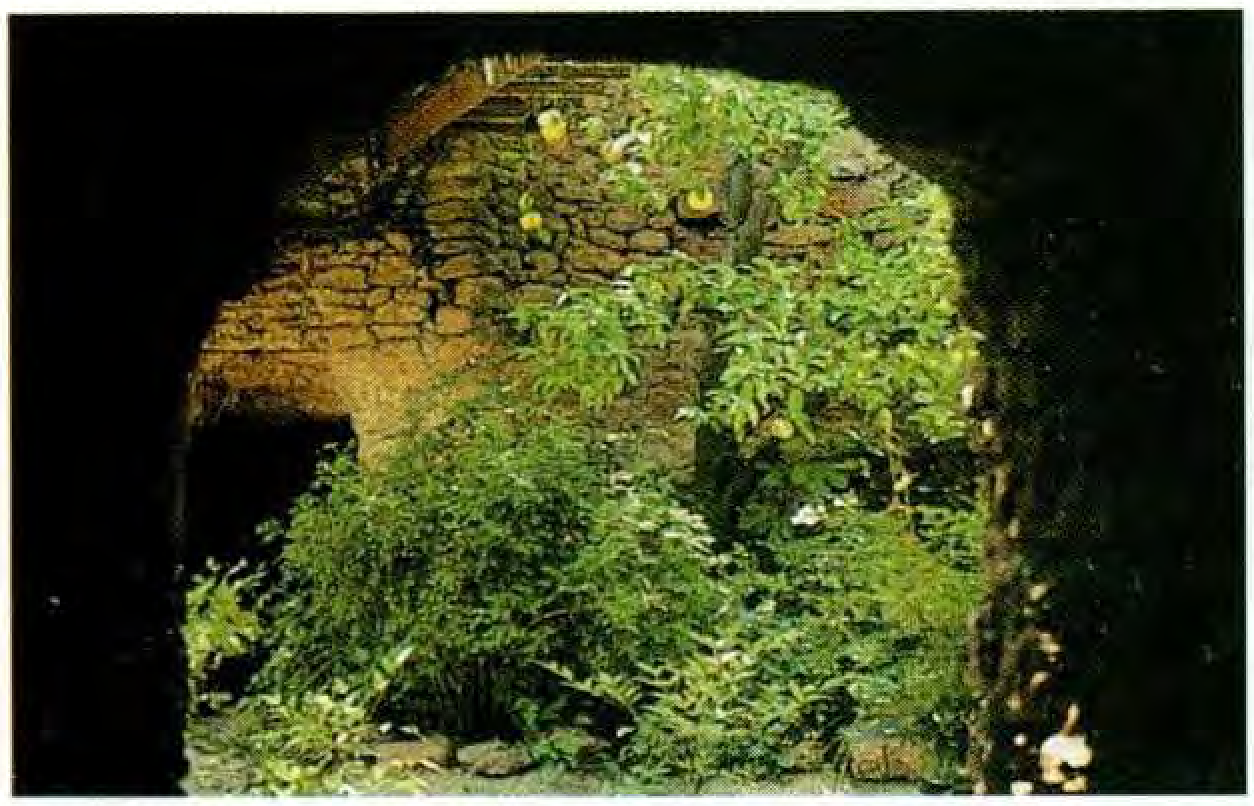
74. KOONIBBA, SA, AUSTRALIA.
Dust storms in settlement carry infectious diseases, bacteria, encephalitis, and cause about 40% of sinus or asthma problems, and sore throats. These broad N–S streets need paving or re–alignment, windbreaks, or zig–zagging. Houses are dust–filled by winds.

75. ALICE SPRINGS, CENTRAL AUSTRALIA.
Extensive disc pitting over 600 square km has reduced dust storms around the town.

76. DETAIL OF NUMBER 75.
Detail of grasses in pits.

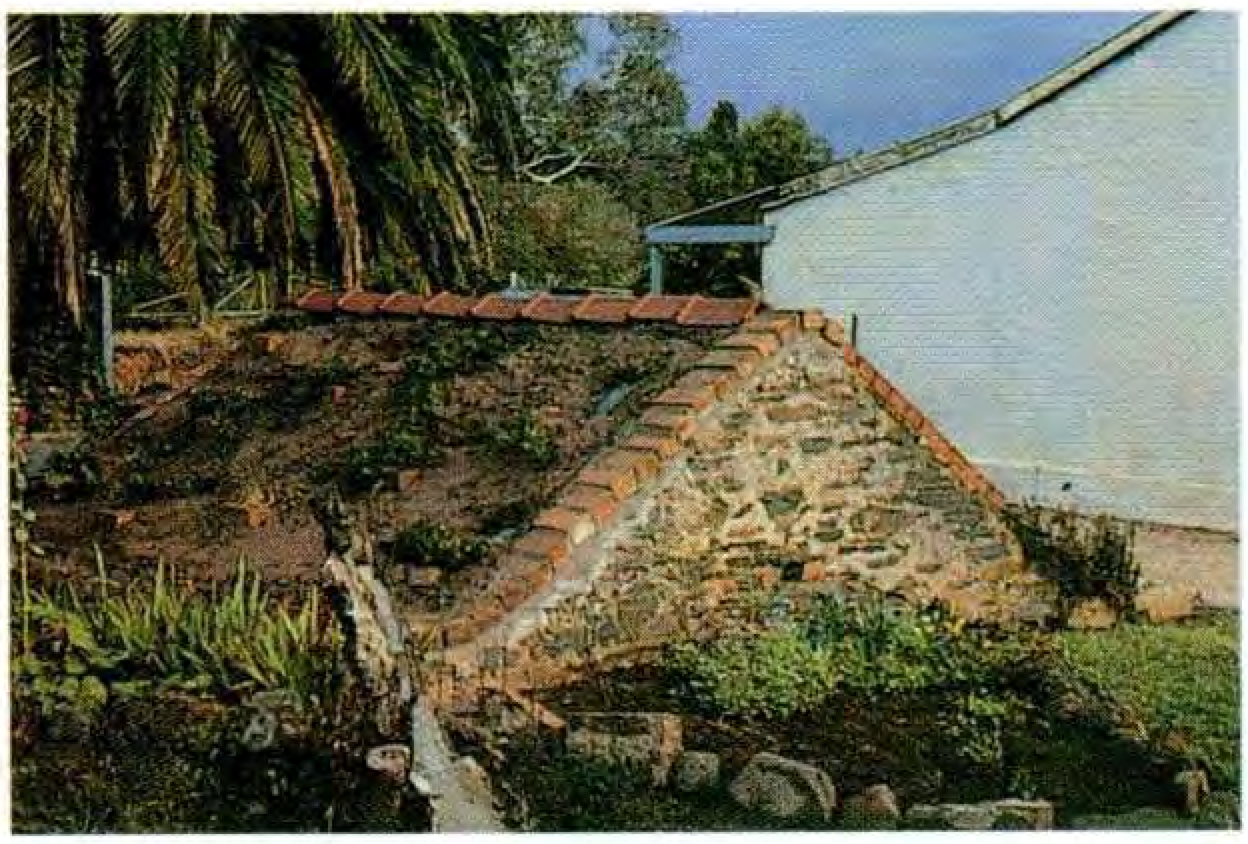
77. NEAR ASPEN, CO, USA.
Traditional earthed–up barn in high cold desert affords winter hay storage and shelter for livestock; such barns are insulated by snow.

16. DRYLANDS
Building And Settlements



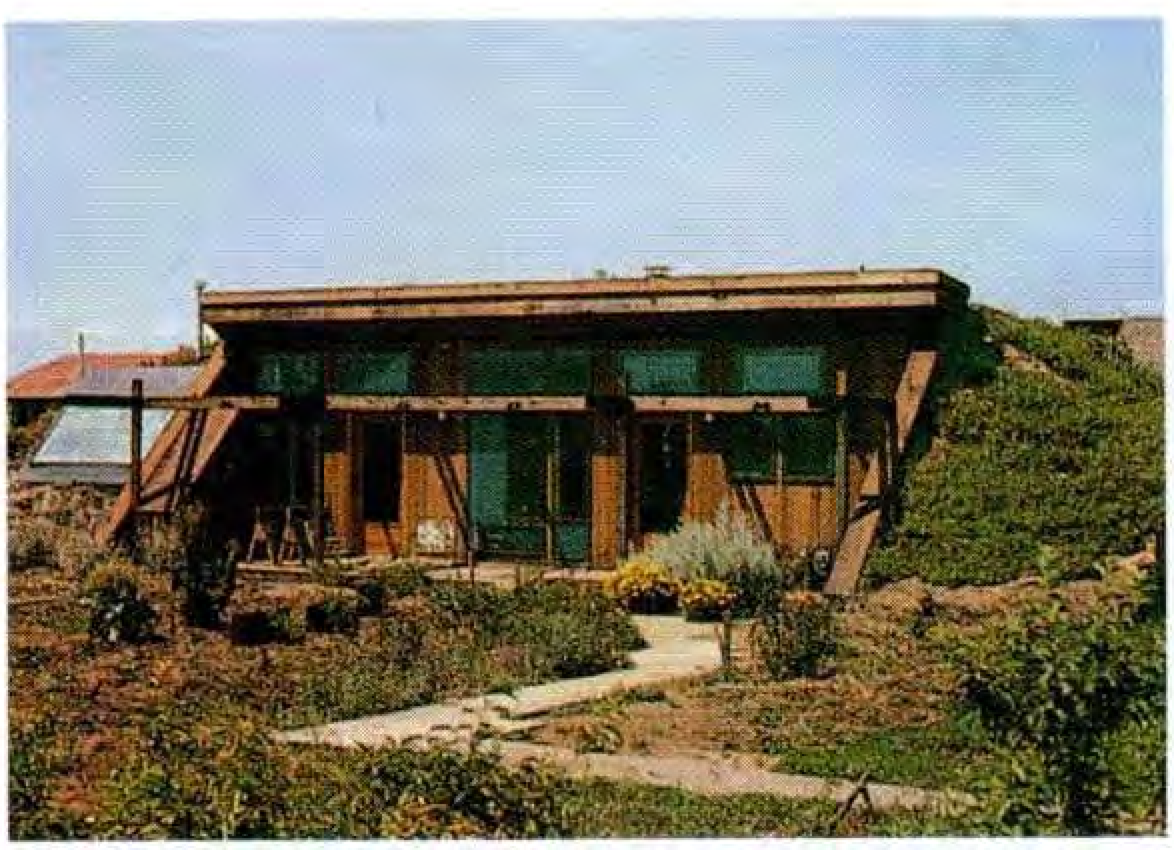
78. FRESNO, CA, USA.
Underground orchards; hand–dug caves open out to shaded pits containing fig, grape, citrus, and pomegranate. This house covers 2.8 ha and was hand–dug by M. FORESTIERI.

79. AS FOR NUMBER **78**
Looking up from underground, the sky is covered by oranges; roots in pits are cool, easily mulched. The ground surface can be funnel–shaped to catch water and direct it to plant containers.



80. GREENOCK, SA, AUSTRALIA.
Traditional buried dairy shed keeps milk and food cool. Vine, earth, or tree shade assists cooling.

81. OLD SNOWMASS, CO, USA.
Early experimental version of The Windstar Foundation's "Biodome" uses solar electricity, heating ponds, domed greenhouse to grow tender crop year–round in high (7,500' ASL), cold, dryland where the growing season averages 60 days. Frogs and finches help with pest control in greenhouse, *Tilapia* and hydroponic vegetables are grown in the ponds.



82. VILLAGE HOMES, DAVIS, CA, USA.
Earth–sheltered house with solar hot water, turf roof, and slab floor, provides good comfort control in the house.

83. Roof of house in Number **82**; ice plants and herbs provide active cooling by transpiration and shade.

84. LAS PALMAS, CANARY ISLANDS.
Opuntia provides fruit (Tuna), vegetable food, cattle forage, hedge, and is here hosting the Conchineal scale, used locally for food dyes.

85. ST. THERESA MISSION, CENTRAL AUSTRALIA.
House verandah is screened with Bryonia (a cucurbit), Lab–lab bean, and tomato vines. Such screens cool west and sunward walls, and are sustained by waste wash–water and grey water.

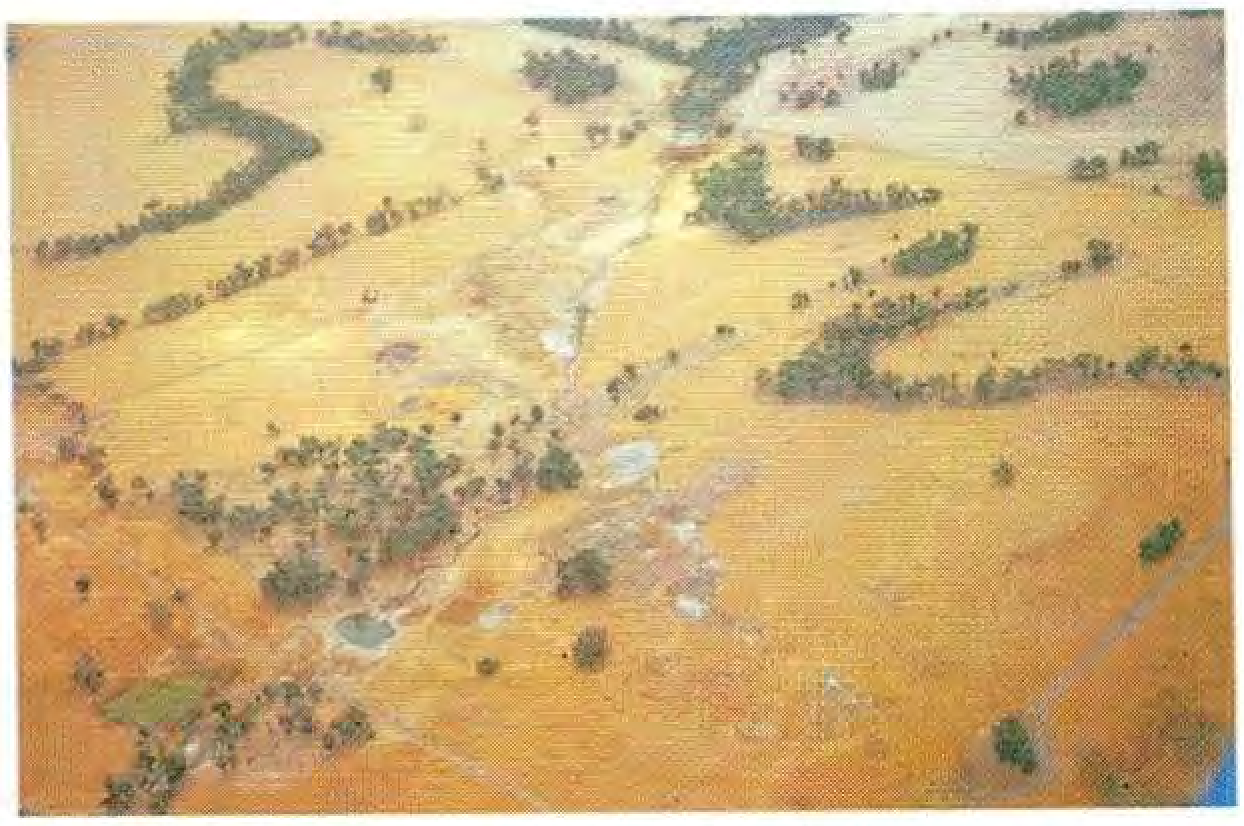
86. LAS PALMAS, CANARY ISLANDS.
Apple and pear crop is sustained by a deep (0.3 m) mulch of *Enarendo* (deep cinder) technique using volcanic cinder to produce fruit, potato, and vine crop in an area receiving mainly night fog and condensation moisture.

87. ST. THERESA MISSION, CENTRAL AUSTRALIA.
Gidgee *(Acacia cambagei)* creates a desert mound or *Nebka* about 1.5 m high and 12 m across. Many sessile or weeping trees in deserts will cause dust accretion in this way. *Acacia spp* in the Kalahari do the same, providing deep absorbant soils and mulch for vines, other trees, and burrowing animals.

88. LAS PALMAS, CANARY ISLANDS.
Many desert *Acacia spp* provide abundant poultry seed, as do *Lycium spp* and *Solanum spp*. Here, *S. lidii* provides abundant fruit and seed suitable for chicken forage; many woolly *Solanum spp* provide dryland fruits or pot herbs.

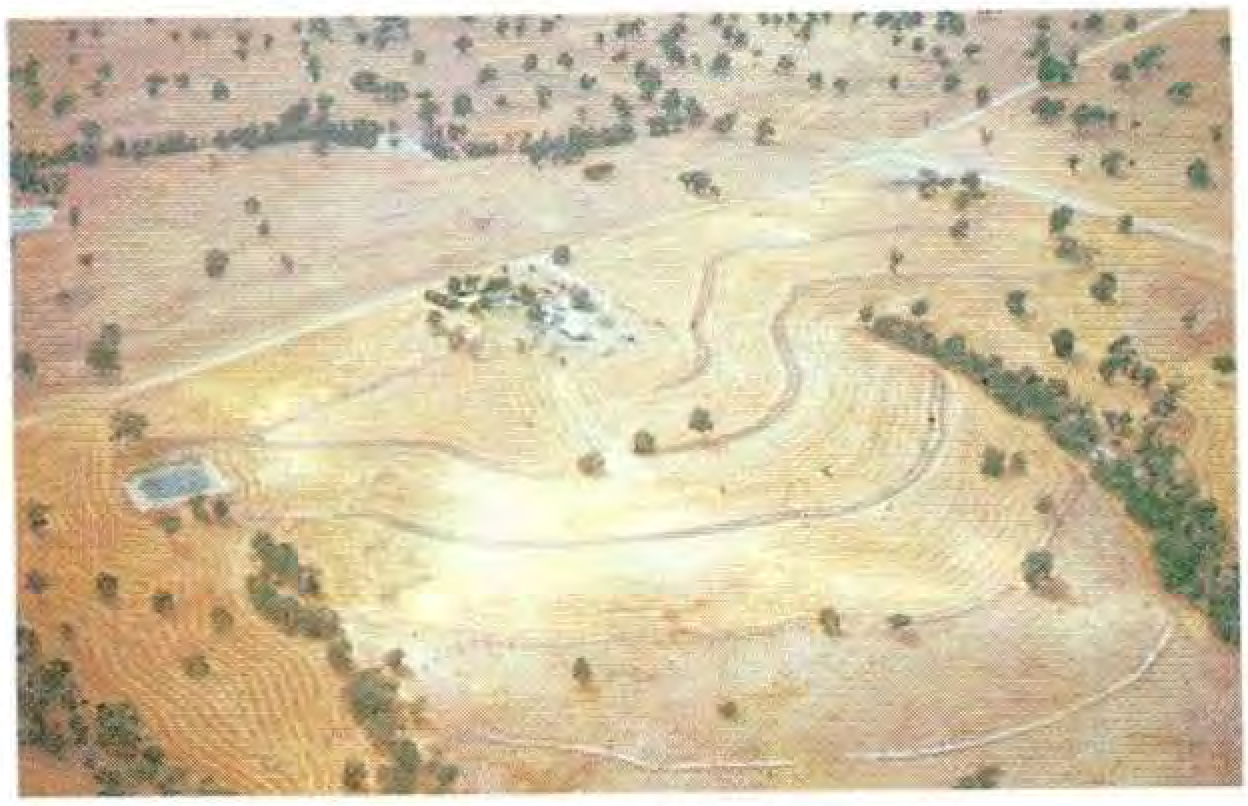
89. TUCSON, AZ, USA.
A spiny *Ocotillo* hedge guards an O'o'dam (Papago) garden. This species is cultivated for fencing, can be liveset to grow it irrigated, and is widely used as a reinforcement or base for mud wall construction. It is a useful crop in itself for desert structures.

18. DRYLANDS
Salting and Interceptor Banks



90. BODLINGTON AREA, WA, AUSTRALIA.
Deforestation, grazing, and wheat cultivation have produced widespread salting, here visible as collapsed soil at seepage lines. The brownish barley greas *(Hordeum maritimum)* is also indicative of soil collapse.

91. NEAR QUAIRADING, WA, AUSTRALIA.
A closer look at a once–forested marsh in wheatlands, now a saltpan.



92. QUAIRADING, WA, AUSTRALIA.
A farmer develops interceptor banks to run surface water and throughflow off fields to a natural valley, thus isolating soil blocks for rain leaching and preventing a "cascade" effect downhill of salty overland flow or throughflow.

93. QUAIRADING, WA, AUSTRALIA.
A classic interceptor bank, ending on the streamline as marked by the distant trees. A bulldozer has rammed subsoil on the downhill wall of the bank. Depth = 1.5 m, width 4 m, spacing not more than 100 m apart, or (on slopes) 1 m vertical separation. Soil pit below this bank shows no throughflow, no rising salted groundwater.

94. BEERMULLAH, WA, AUSTRALIA.
An interceptor has prevented soil collapse by flooding (note rushes on upslope side), thus protecting crop below the bank. Spike rush *(Juncus)* is another indicator of imminent soil collapse, surface flooding, and anaerobic soils. Subsoils are dry, cemented, or subject to groundwater rising.

95. BEERMULLAH, WA, AUSTRALIA.
A series of interceptor banks in wheatfields isolate soil blocks from overland flow and salting effects.

19. COOL TEMPERATE
Establishing Systems

96 and **97**. COLLINGWOOD RIVER, NEW ZEALAND.

Rampant gorse covers 280 ha; lines are rolled down or slashed and eucalypt, pines, and acacia are planted by DICK NICHOLS. "Zone 1" is fully cut and planted to pioneer trees; Tamarillo cuttings can be planted directly into the slash.

99. NELSON, NEW ZEALAND.

DICK ROBERTS uses gorse as "rough mulch" to protect fruit and forage trees in steep sheep pasture; reduction of a "weed" species protects the succeeding crop. Tree crops will shade out gorse if thickly planted as in Numbers **96-98**.

98. AS FOR NUMBERS **96** AND **97**.

After 2-3 years, the remaining gorse is slashed, and mature rainforest species self-seed into the forest floor. After 5-6 years the gorse has rotted, and rainforest establishes under acacia (which in turn is felled); native birds carry in rainforest seed.

100. KATJIKATJIDARA, CENTRAL AUSTRALIA.

Fallen trees, here near a desert inselberg, provide protection from feral animals for young trees and for Andrew to establish a food tree in the branches.

101. MAHALAPYE, BOTSWANA.

Fierce thorny mulch from *Acacia tortilis* protects new trees from intense browsing pressure in compounds, here planted by DOROTHY NDABA.

102. TAHEKE, NEW ZEALAND.
Avocado in" hard" frost area thriving in a clump of tagasaste. Kikuyu is slashed to provide additional mulch at JIM and MIRIAM TYLER'S farm. The tagasaste yield upto 7m of mulch trimmings per annum.

103. CANTERBURY PLAIN, NEW ZEALAND.
Tagasaste drilled with turnip for future sheep forage; seedling trees establish through turnip (brassica) crop at MATTHEW CARPENTER'S property.

104. BANKS PENINSULA, NEW ZEALAND.
1 m in row, 2 m between rows, tagasaste provide summer forage from coppice and short–period browsing by sheep. Grasses thrive between rows (DSIR trials by DOUG DAVIES).

105. BANKS PENINSULA, NEW ZEALAND
Pampas grass is both fast shelter for lambing ewes, and a preferred forage for most livestock; propagated by divisions. Combines well with tagasaste strips.

106. STANLEY, TAS, AUSTRALIA.
Tomatoes in a keyhole bed sheltered by a windbreak of sun root (Jerusalem artichoke) in old tyres on a cold and wind swept site.

107. STANLEY, TAS, AUSTRALIA.
A herb spiral in the form of a ziggurat provides ample culinary herbs at the kitchen door; drainage and aspect suits most cool area species of herbs (spiral 2 m across, 1 m high).

21. COOL TEMPERATE

108. BLACK FOREST, WEST GERMANY.
Traditional integration of home and winter barn; mature mixed orchard. Even the bees are housed in this region in winter. Note earth ramp to upper floor of barn to assist hay storage.

109. NEAR CHRIST-CHURCH, NEW ZEALAND.
Willow coppice crop, here intended for basketry, can also be used for medicinals, forage, "stickwood" for radiant (mass) heaters, active charcoal filters, artist's charcoal, and so on. "Willow water" (fresh chips soaked in water) provides gibberelic acid for promoting root growth in the striking of cuttings.

110. NEAR CHRIST-CHURCH, NEW ZEALAND.
The willow coppice field as for **109**.

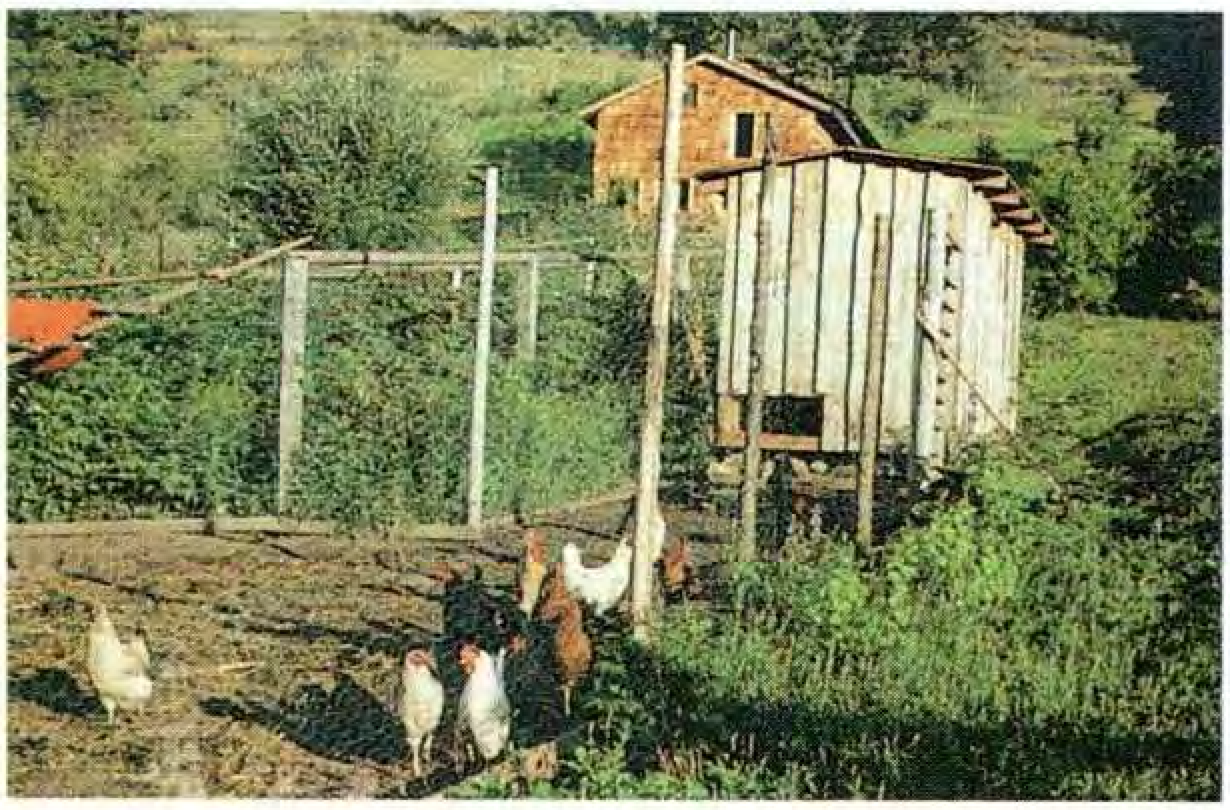
111 PERTH, TAS, AUSTRALIA.
Here, willows are pollarded for propagation cuttings at a nursery.

112. NELSON, NEW ZEALAND.
Matsudana willow provides strict windbreak for a kiwifruit vine crop on the plains near Nelson. The strict form allows minimal space loss on the ground and needs little maintenance to control shape.

22. COOL TEMPERATE
Small livestock

113. FOREST, TAS, AUSTRALIA.
A rabbit cage "tractor" cleans clover and grasses from mounded strawberry crop at MICHAEL MANGEVELAKIS' farm. Rabbits are part of the yield of the weed system, and provide manures for the strawberrries.

114. STANLEY, TAS, AUSTRALIA.
Lycium ferrocissimum hedge carries vines of hops, banana passionfruit, and shelters main crop pototatoes. Its berries are loved by poultry and being a sharp thorny shrub (used to keep out lions in Africa) provides ideal shelter.



115. LAKE CHELAN, OKANOGAN, USA.
Chickens "tractor" grasses for small fruit (background crop), "weed" small fruits over the autumn period, and provide manure. At MICHAEL PILARSKI'S (Friends of the Trees Coordinator) farm.

116. ASPEN, CO, USA.
Chicken-heated greenhouse and solar-heated seedling cloche enable early planting in short season high mountain areas.

117. WILTON, NH, USA
Turkey forage below autumn olive *(Elaeagnus umbellata)* with abundant berries. Siberian pea shrub *(Caragana arborescens)* and autumn olive are important tree forage legumes of cool and cold climates.

118. CALDER, TAS, AUSTRALIA.

JIM BASSETT confines his rampant thorny blackberry (35 kg/year yield) in a straight-jacket of old oil drums which also makes for easier harvesting.

119. KIEWA, VIC, AUSTRALIA.

GEOFF WALLACE observed a free-seeded apple in blackberries on his farm. His cattle demolished the blackberries to get to the apples. He now plants apples in the brambles (part of a natural guild in England), they prosper in their protected hole, fruit, and soon the brambles are trodden down by cattle eager for sweet apples.

120. CLE ELUM, WA , USA.

Clearings in fir forest maintain high production of berry fruits, fungi, and nettles all an important crop to the SALISH indians. Here, filberts, thimbleberry, black raspberry, huckleberry, wild strawberry thrive.

121. WHIDBEY ISLAND, WA, USA.

Stumps of firs grow many berry species, and slabs from fir stumps and logs generate berry clumps on lawns or in clearings, as do fallen fir logs. Birds bring seed and manure to stumps and they establish protected from deer browsing.

122. TUMBARUMBA, NSW, AUSTRALIA.

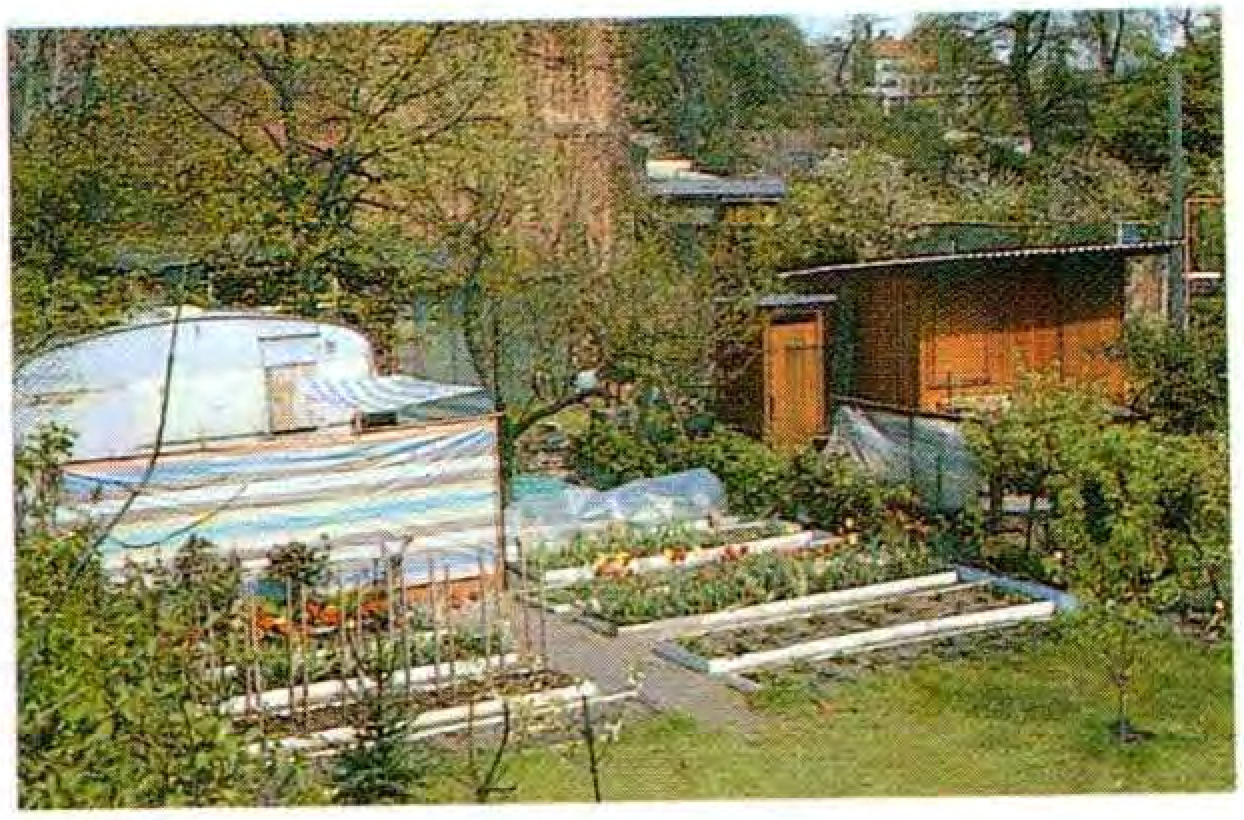
NEIL DRUCE and JASON ALEXANDRA reduce fuels in a "Jean Pain" chipper. Chips are mulched, composted, and fermented to methane. Mechanical removal of forest fuel reduces the fire risk and enriches soils unlike "cool burns" which impoverish soils and often lead to wild fires.

123. EVERGREEN COLLEGE, WA, USA.

Cloche raises early tomatoes in leaf mulch; sides are hinged to allow late spring growth of crop. RENY MIA SLAY.

24. URBAN

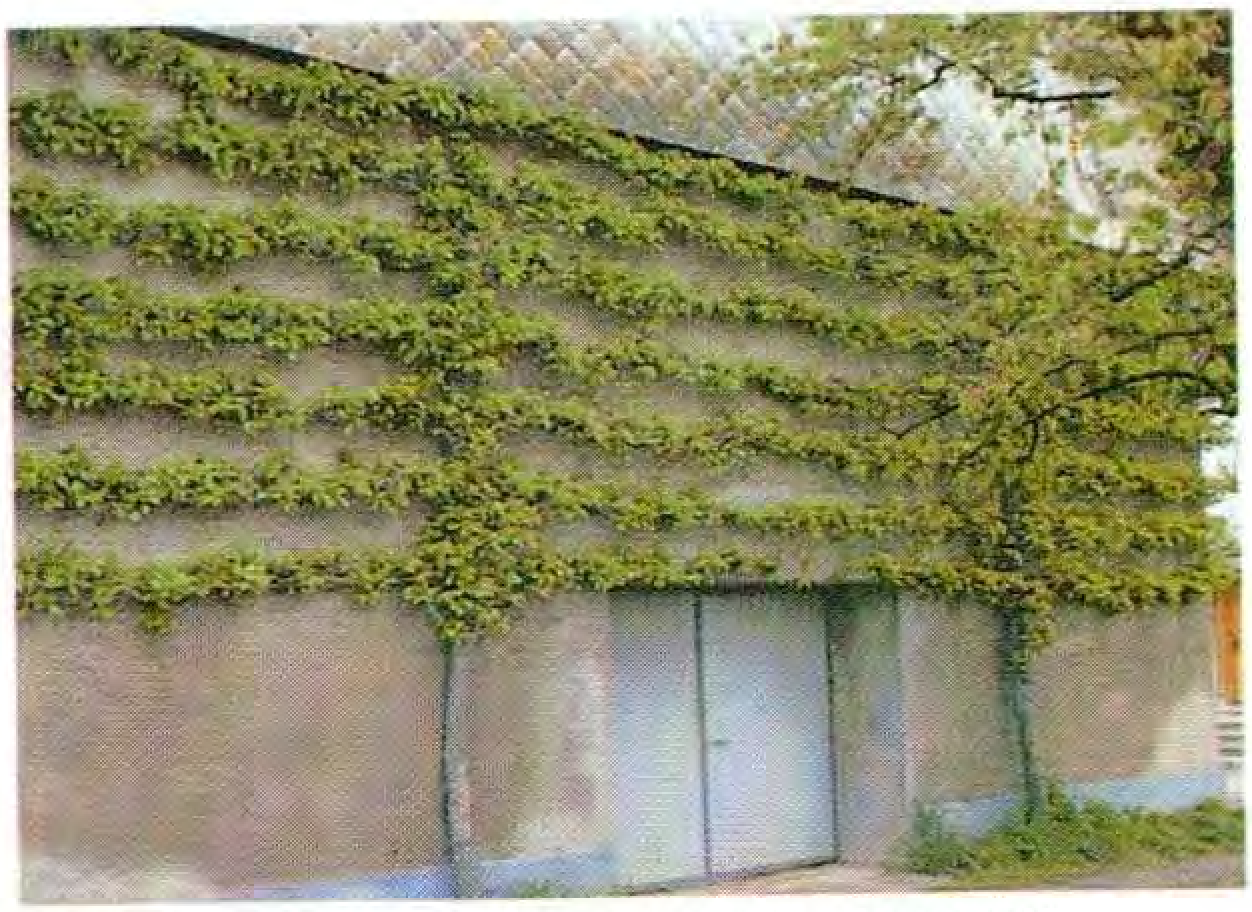
124. THE BRONX, NY, USA.
The Green Guerillas transform vacant land in urban wastelands to productive, beautiful, and recreational usages as city farms.



125. WEST GERMANY.
The productive Schreber gardens adjoin almost every settlement and provide food and much–needed recreation in cities. People are permitted to spend weekends on these mini–farms. (One example of greening the cities).

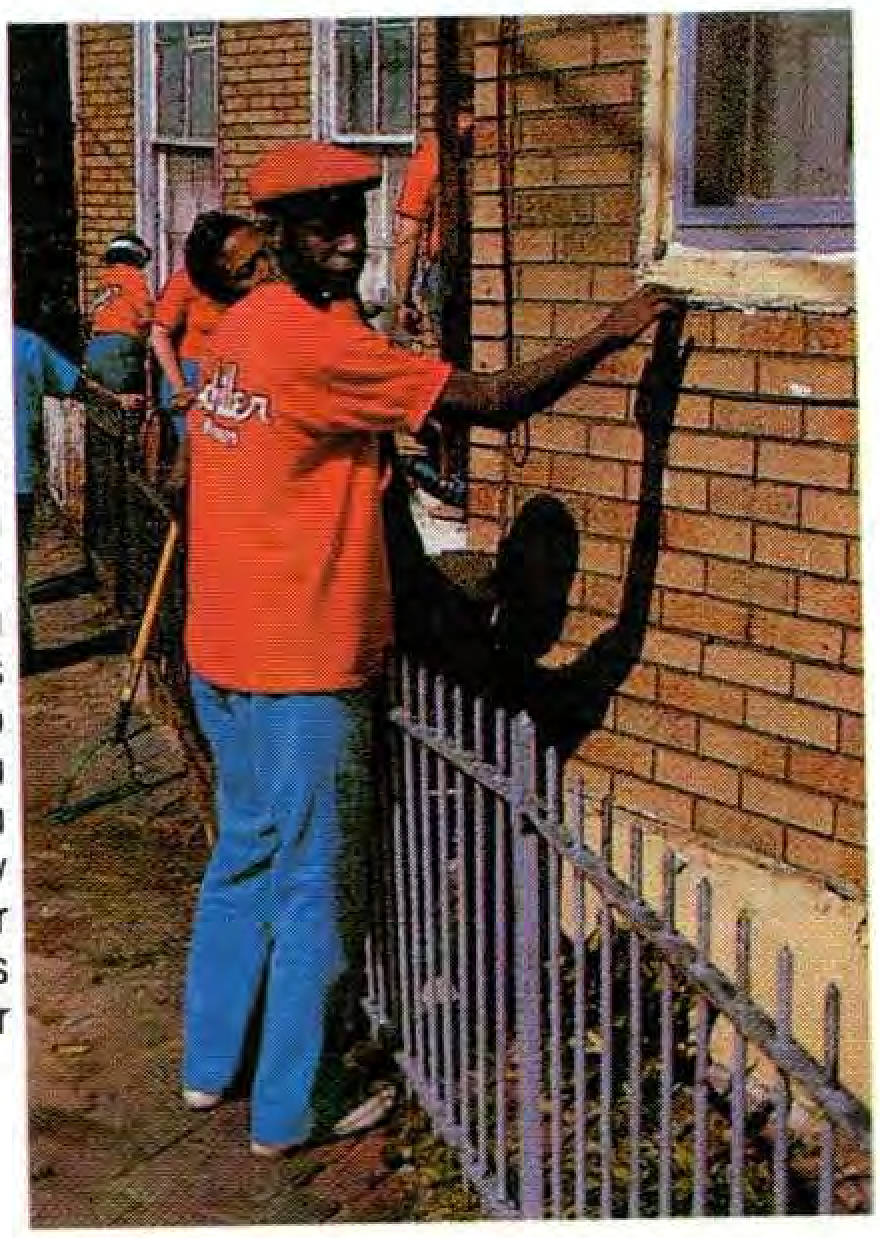
126. GLIE FARM, SOUTH BRONX, NY, USA.
This urban farm provides 8% of New York's herbs, and provides employment for many people in an area of urban decay.

127. THE BRONX, NY, USA.
The only example of productive use of New York's food waste is this small composting business operated by "The Bronx Frontier" group. Small mountains of compost are sold off site to create meadows over rubble–filled wastelands.



128. BLACK FOREST AREA, SOUTH GERMANY.
West or sun–facing walls in cities and towns provide radiant heat for marginal crop here an espalliered pear grows well and "softens" the wall of an urban barn. We can therefore regard most urban buildings as *additional* agricultural space as are trellis systems over alleys, shopping complexes, up building walls, etc.

129. LOUISVILLE, KT, USA.
Project WARM volunteers retrofit and insulate old folks' homes by the thousand. This sharply reduces energy costs and deaths from the cold. The cost amortizes in two winters. Only minimal funds are directed to such sound expenditures in western society. It is always cheaper to conserve rather than gernerate energy. Such projects make many dangerous or dirty power generating systems obsolete (e.g. nuclear power).



trimming. All of these protect diversion banks and compounds from grazing animals. *Euphorbia* takes root from cuttings in even arid conditions, and *Acacia tortilis* is ideal for cut– and–build fences. When cutting *Euphorbia*, be sure to protect the eyes with goggles, and keep the skin covered if allergic to the milky sap.

Windbreaks

Primary tall windbreak of *Araucaria*, *Cupressus*, *Casuarina*, *Pinus*, hardy *Phoenix* palms, and even mangroves may be needed in front-line locations, followed in the lee with such hardy quickset species as *Euphorbia tirucalli*, *Coprosma repens*, *Echium fastuosum* and so on. It is always best to find local plant species that do well in the district.

Erosion Control

Contours at 10 m on medium slopes (2–7°) and at 5 m on steep slopes can be planted out with root sets of *Canna*, Vetiver grass, lemongrass, or pampas grass. These are set out at 0.3–0.6 m spacing and form an unbroken cross–slope hedge, or a crown on earth walls or dam banks at spillways (**Figure 10.13**). They both disperse water and create silt traps; behind such self–perpetuating walls, soil is deeper and trees can be planted or crops grown. The system is cheap, effective, and provides mulch. Some of the yuccas, agaves, and aloes may provide the same structural effect in desert areas.

10.7
INTEGRATED LAND MANAGEMENT

The Maori *marae* or Hawaiian *ohana* were geomorphic and sociological units in which land and people were integrated for sustenance. They may have evolved out of early errors of over–clearing, excessive burning, and the extinction of useful animals before reaching equilibrium. We can only hope that the modern world also has time to take stock and come to its senses, but that will rely on determined change by many thousands of us within society.

Presuming a hill–to–shore profile (often a volcanic cone profile, **Figure 10.28**), the stable tropical landscape may require some or all of these features:

• PROTECTED SKYLINE AND HILL FORESTS. These not only protect soils and waters, but both mine and release plant nutrients from the upper (sometimes steep) slopes. They can be used as limited forage resource and mulch provision, but should have iron–clad protection. Their clearing brings compound catastrophes ranging from landslide to loss of nutrient in water and crop, desertification, and consequent severe social disruption. At the base of these forests, as the slope eases to 15° or less, water can be diverted or harvested to replenish groundwater and irrigate terraces and crop.

• MIDSLOPE OR KEYPOINT. A diversion of stream water here will lead water out to ridges for terrace crop and village use. Thus, cropping commences below this critical point. Human occupation and complex cultivated forests and gardens can now be established downslope. The stable plateau, the hill rising above the valley, and bench sites above the reach of flood and sheltered from hurricane and tsunami are prime cluster settlement (village) sites, with some scattered housing higher on ridges and the forest edge.

• LOW SLOPES (2°–15° slope) are well suited to earth–shaping as terrace and padi, with limited grazing and innovative forestry. These are the sustainable agricultural areas, where attention to sub–contoured agriculture, windbreak, and access will help direct run–off and water to crop.

• COASTAL FLATS AND VALLEY FLOORS. Rich and often deep humus soils can accumulate on valley floors. Greywater and processed manures from settlement and livestock add to fertility, where extensive aquacultures or rich forest/orchard crop can be developed.

• SHORELINES are preserved for 100 m (330 feet) or so inland for essential windbreak, shore stability, and cloud generation over land. Selected quiet harbours and refuges accept fishing settlements based on sea resources. Shores with 15–20 year *tsunami* history need sacrificial palm/*Casuarina* barriers to reduce storm damage ashore. There may be lightly–built and temporary shore housing, which is used only when working the coast, with more substantial homes and sheltered gardens safely inland or behind earth embankments. If shallows or a coral–based lagoon/reef system stretches offshore, the following categories of use also apply.

• LAGOON AND ESTUARY SEA IMPOUNDMENTS. Ancient and yet innovative sea–walls (usually of semi–permeable coral blocks with entries, flood–tide gates, and a series of inner pens) are an excellent use of the shallows. Restricted mangrove plantations help stabilise the banks and provide sea mulch while catching any silt that washes down from above. These warm–water lagoons are rich in algae and are good sites for cultivated seaweed. They also impound and fatten mullet and mangrove fish, oysters and eels, shellfish and prawns. In the sea lagoons, mobile phosphates are fixed in plants and mud in a few days, and are then available for growth. Such rich estuaries are invaluable as managed maricultures.

• MARINE CONSTRUCTS. Artificial reef systems of tyres (on sand), coral blocks, and boxes of palm trunks greatly enlarge the habitat for sedentary fish and lobsters; within a year, these constructs are consolidated or cemented by corals. Weak electroysis on metal mesh creates an artificial but permanent coralline deposit more rapidly. In extensive sandy shallows, log barriers full of sand and stabilised with mangroves provide shore barriers, lagoon walls, and "edge" in the sea.

It is as well to have an integrated concept of appropriate land use in mind for both broad policy

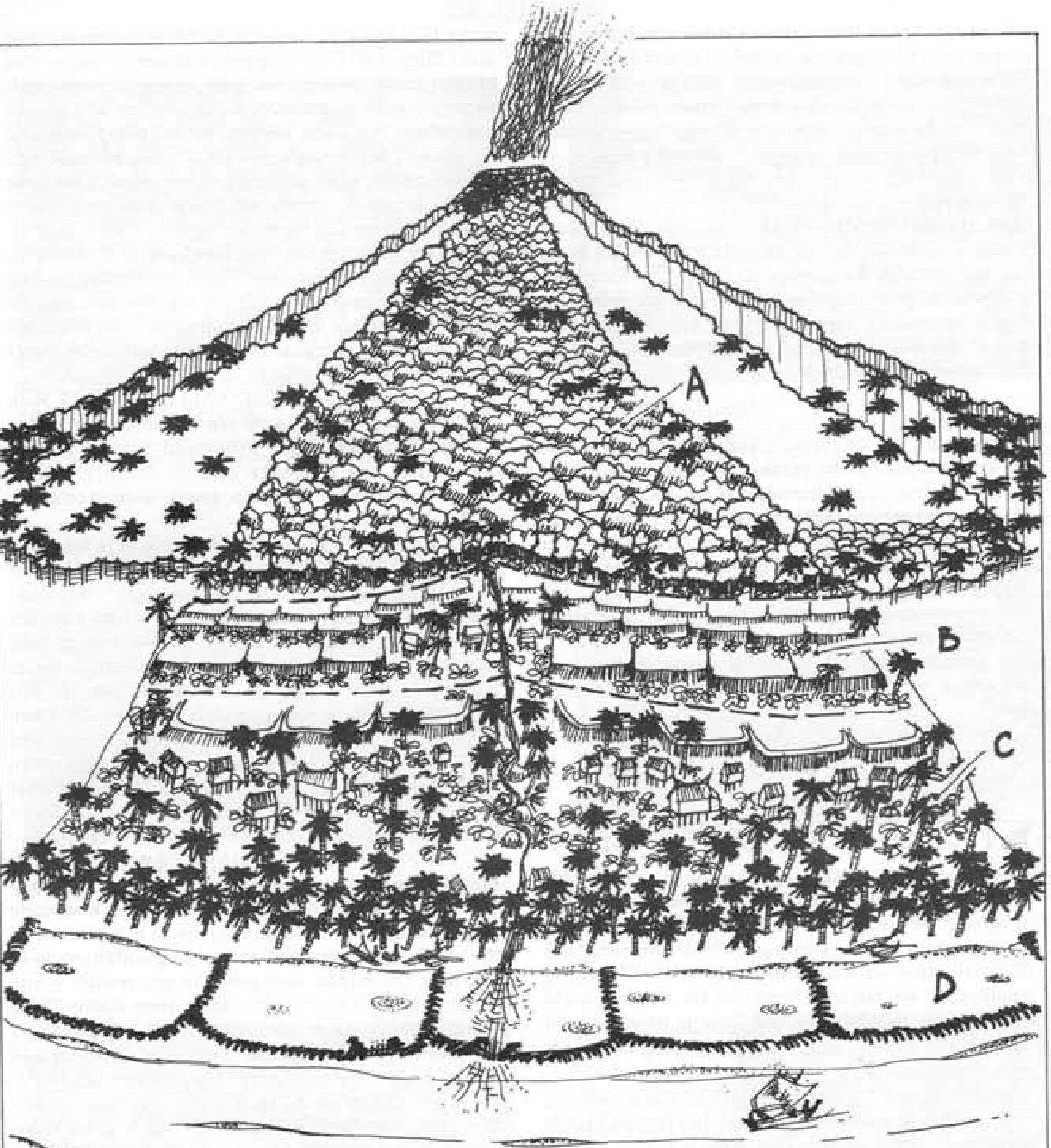


FIGURE 10.28
OHANA SYSTEM (Hawaii).
One radial valley of a volcanic island. A - "taboo" forest of upper slopes; B - stream diversion to ridge or high terraces, main village; C - sacrificial forests of palm to modify hurricanes; D - reef fish ponds to retain leached nutrients, growing mullet and shellfish; E - reef modified with coral blocks to shelter crayfish, fish.

planning and future land redistribution. There are slow moves in present government circles to institute some sanity into life and landscape, as (like agriculture) government must change towards an environmentally sound policy.

10.8
ELEMENTS OF A VILLAGE COMPLEX IN THE HUMID TROPICS

Based on traditional and modern villages, a complex can be built from the following checklist:

- A well-arranged array of housing, often grouped around a compound.
- The compound has processing and storage areas, threshing floors, dancing areas, meeting house, cooperative or retail store, bulk fuel depots, firewood and mulch depots.
- A well, piped water, tanks, or dam must be sited and integrated for clean water (depends on local skills, resources, water available, and site characteristics).
- A plant nursery to serve gardens and forest.
- At each house, 0.25–1.0 ha of home garden and orchard, based on self-reliance.
- At borders of gardens, ranges for domestic species, e.g. chickens, guinea pigs, ducks, rabbits, small pigs, pigeons; these are a manure resource for the home garden.
- In areas of plentiful water, fish ponds over which some animals are housed.
- Sector or zone of fuelwood plantation, potentially integrated with windbreak.
- A strong yard and sheds for cattle and pigs at a commercial level.
- A careful zonation of tree polyculture as per **Figure 10.29**.
- Special facilities such as a log-trimming or boat-building area, fish net drying racks, canoe or small boat landing, wharf, freezer, solar pond installation, power house, large community drying shed, craft work areas, and vehicle or draught-animal park area.

10.9
EVOLVING A POLYCULTURE

If, as is often the case, we start to evolve a permaculture on grasslands or compacted soils, then the very first step is to thoroughly plan the site, and rip, swale, pit, or dam every area to be planted, thus ensuring maximum wet-season soil water storage to carry over to dry periods. This process should commence at the highest point of the property, and around the house or village site.

On these loosened soils and in mulched swales, a mix of tree legumes, fruits, bananas, papayas, arrowroot (*Canna*), cassava, sweet potato, and comfrey can be co-planted. There should be one such plant every 1–1.5 m, with *Acacia* at 3 x 3 m spacing, banana at 2 x 2 m, fruits 5 x 8 m, palms 10 x 10 m, and the smaller species as gap fillers.

As well, all larger planting holes should be seeded with nasturtium, *Dolichos*, Haifa clover, broad bean (fava), buckwheat, *Umbelliferae* (dill, fennel), lupin, vetch (hairy or woolly), dun peas, chilies, pigeon pea, or any useful non-grass mix available and suitable to climate and landscape. The end aim is to completely carpet and overshade the ground in the first 18–20 months of growth.

Ideally, dense plantings of this type should be grass or hay mulched, using monsoon grasses, swamp grasses, and later the tops of arrowroot, comfrey, banana, *Acacia*, and green crop. Later still, shade-loving species such as coffee and dry taro can be placed in any open spots.

Paths for access, openings for annual crop, bee plants on the edges, flowers, and fire-resistant "wet" ground covers such as comfrey, *Tradescantia*, *Impatiens*, and succulents can be placed as time goes on, while the fruit trees are kept free of grass and mulched by cutting out crowded *Acacia* and banana as mulch.

It is far better to occupy a quarter hectare thoroughly than to scatter trees over 2 ha as production is higher and maintenance less, moisture is conserved, and frost excluded.

As for species richness, or species per hectare, this can be very complex and dense near the village or home, and simplify to well-tested species of high yields as distance from the home increases. Any trellis crop should be first placed to shade the home, livestock, or to make fences, and only later placed on *Acacia* or other legumes as they age.

The number of productive, managed and effectively-harvested species in a polyculture is decided by a complex of these factors:

1. The number of people responsible for managing one or two of these crops or animal species (labour).
2. The proximity of the complex to village or settlement (zoning).
3. The relative cost-benefit balance on increasing inputs to optimum levels (fiscal economics).
4. The need for effective plant guilds (harmonious ecological assemblies).
5. The method of marketing and processing (whether these can cope with complex product).
6. The total area which is controlled. Larger areas demand increasing simplicity, at a cost to factor 4 above.
7. The maturity or stage of evolution of the plant system. Older systems provide more niches, younger systems more regular product.

In practice, the gardens, walls, roof areas, trellis systems, and compounds of villages are the most complex and rich areas of cultivated species. We can manage, and find uses for some 200–400 species in such situations, of which the following usage classes are dominant (some very useful species fall into 3 or more of these classes):

Potential Species

• Basic food species	70–90
• Mulch and fodder provision	10–30
• Medicinals and biocides	20–50
• Structural and craft	5–20
• Culinary herbs	20–30
• Beverages and export specialities	10–15
• Fuelwood and coppice	12–30
• Special uses, sacred uses	8–15
Total cultivated species	155–280
Plus wild–gathered species	40–80
Total species utilised in a complex village situation.	195–360

While a complex polyculture of many hundreds of species delights both the naturalist and (in food plants) the householder or villager, and the benefits to settlements are numerous, it becomes difficult to control an *extensive* rich polyculture and collect its Our very complex polycultures work best at small scale and with close attention from people. The depopulated, dehumanised, and now almost deserted wasteland of modern agriculture is unable to cope with any but the most basic and simple intercrop systems, thus sacrificing yield, quality, stability, and inevitably people.

Thus, if we analyse the dollar economics of such systems, there will be an optimum number of species

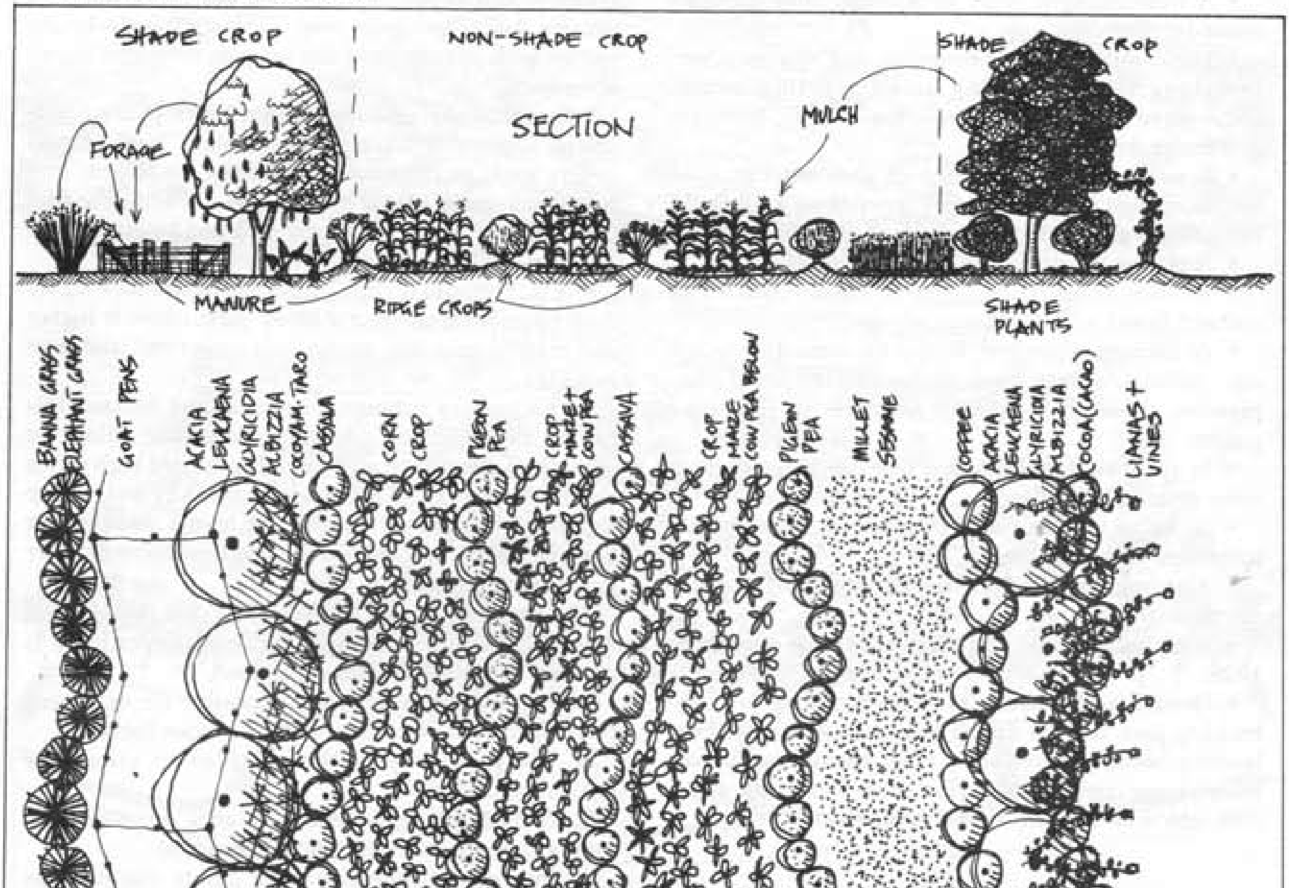
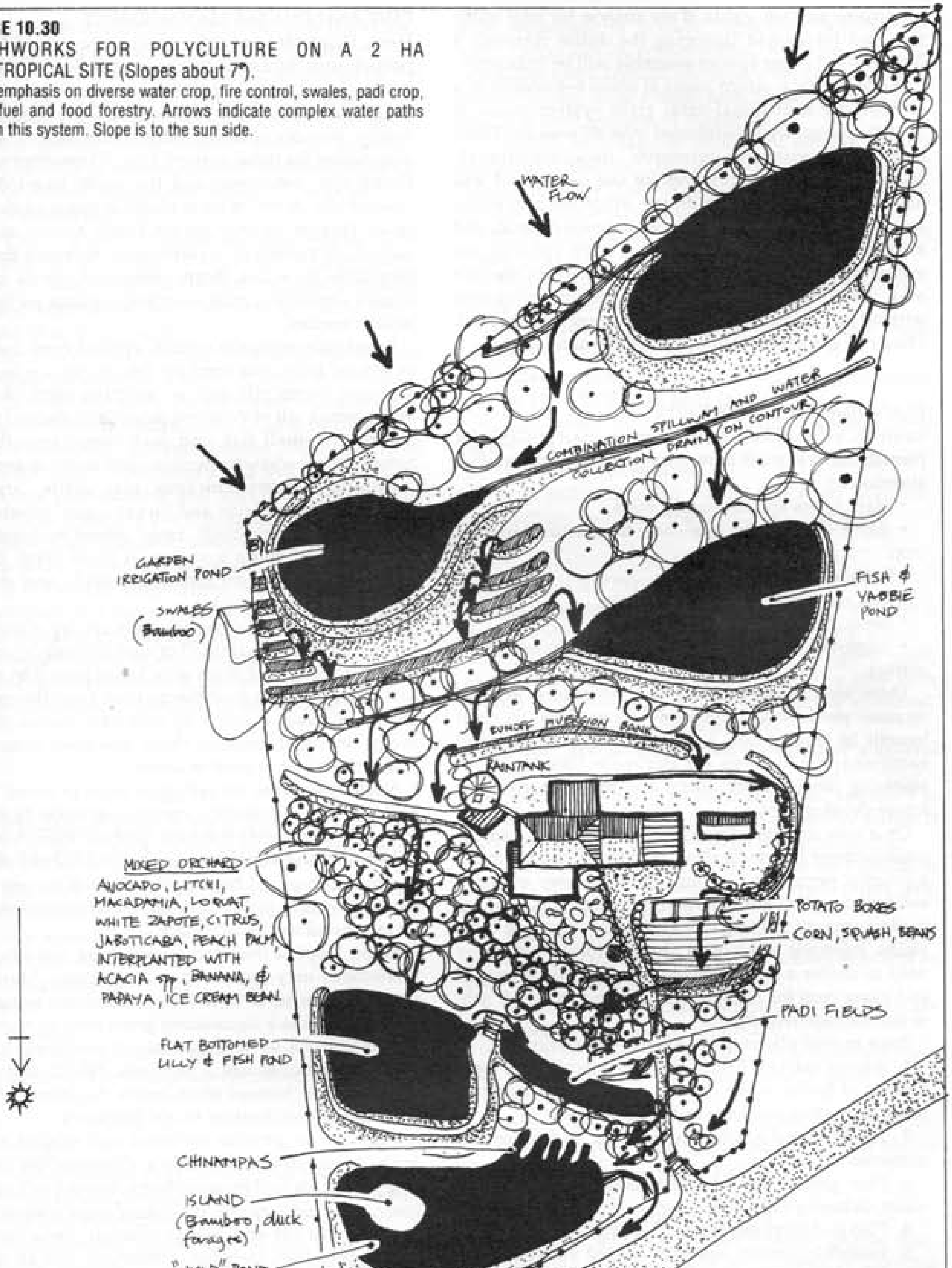


FIGURE 10.29
NIGERIAN POLYCULTURE FOR HUMID TROPICS.
Includes pig or goat pen and forage crops appropriate ridges for cassava, strip crop, zero runoff; contour layout. [Data from Gkiebo and Lal].

FIGURE 10.30
EARTHWORKS FOR POLYCULTURE ON A 2 HA SUB-TROPICAL SITE (Slopes about 7°).
Heavy emphasis on diverse water crop, fire control, swales, padi crop, dense fuel and food forestry. Arrows indicate complex water paths through this system. Slope is to the sun side.



for broadscale cash yields. If we analyse for total nutrition and total yield (ignoring the dollar returns), a different and richer species assembly will be indicated.

While the fiscal return peaks at about 6–8 species in a system, the nutritional–total yield system peaks at 50–100 species, well–distributed over all seasons. These two factors (extensive–intensive, fiscal-nutritional) must be defined by ourselves for our needs, and will have a profound effect on design. What we may arrive at is a sensible zonation of species richness close in, and a concentration on less species of high value as we extend the system. It is in the garden, however, that we may learn the value of such successful extension without sacrificing large amounts of energy and capital. Thus, our gardens are trial areas for the outer zones.

PLANNING THE WHOLE SITE

Even in established polycultures, particularly in plantations, it is good to re–survey the site with special attention to:

- Main access and harvesting ways.
- Earth–shaping for rainwater harvest and specific crop.
- Sufficiency of mulch.
- Best water and irrigation strategies.
- Better village planning.
- Improved or more sophisticated site processing for market.

These are the main factors that can reduce work or increase yields and commercial values. There is great benefit in testing new legumes, tree varieties, and earth–shaping systems for optimum yields, and in assessing labour, work, social and market factors for future development.

On a new site, the same considerations hold, but the establishment of windbreaks and any earth–shaping is a priority, preceding planting. There are also essential soil tests for plant nutrients and trace elements, as it is a modest amount of these that give early vigor and early yields. Intercrop selection is also a priority, sometimes used to shelter a more delicate crop, but also as mulch and nurse crop for nitrogen fixation and for wind, salt, or sun damage reduction.

Steps in total planning are roughly in priority:

1. Assess market; future; prices; potential for processing to higher value; labour; shares, legal systems; social necessities and local self–reliance needs.
2. Analyse and get advice on soils and necessary nutrients.
3. Plan ground layout and windbreak, access, and water. Detailing can follow later.
4. Plan and carry out essential earthworks.
5. Establish nursery and use selected varietal forms for new or replacement crop.
6. Commence broadscale placements with or after windbreak and nurse crop.
7. Continue by constant assessment, consultation, feedback and innovative trials. Fill niches as they evolve.

PEST AND DISEASE MANAGEMENT

Here, I consider only the species we can add to the polyculture to assist in the regulation of problem species (plant and animal). Some powerful biocides that are found in plants are harmless or short–term and are totally bio–degradable, natural substances. Classic insecticides are those derived from *Chrysanthemum* spp, *Derris* spp (rotenone) and the neem tree (*Melia* or *Azadirachta*). A few of these plants in home gardens and small clumps in crop give a ready source of insect control, or control of invertebrates, nuisance fish, and amphibia in water. Both neem and derris control aquatic organisms; most insecticidal plants are lethal to aquatic species.

Broadscale mosquito control, applied from the air or as ground mists, can combine fats or oils (e.g. lecithin), a poison (neem oil), and an infective agent (*Bacillus thuringensis*). All of these are potentially assisted in pest control by small fish and such insect predators as notonectids (backswimmers) in open water systems.

Ground foragers (chickens, pigs, cattle, large tortoises) eat fallen fruit and larval insect infestations, while leaf foragers (birds, frogs) attend to infestations in the canopy, as do a variety of small skink lizards. Some lizards (*Tiliqua*) forage for snails and slugs at ground level, as do ducks.

Pasture grubs are eagerly sought out by a variety of birds and small mammalian and marsupial insectivores. Tropical land crabs seek larval insects in mulch, and provide useful food themselves. Even the problem of kikuyu grass is eased by domestic guinea–pigs on range (in small houses); these free trees from grass competition and provide manures.

Neem tree leaves and oil deter pests in stored foods, and have been so used for centuries in India. In short, a little research will indicate plants, invertebrates, vertebrates and common harmless substances of great use in the tropics. I believe that there is no pest problem that will not yield to our applied commonsense and an integrated natural approach.

In any tropical tree crop monoculture, soil fungi and nematodes may become persistent pests. Marigolds (*Tagetes*) often serve to reduce or eliminate nematodes, and *Crotolaria* as a leguminous green crop traps them in its root mycelia, so both these plants need consideration where nematodes are a problem. Mulch and green manures (soil humus) often buffer the effects of these and fungal pests, hosting fungal predators.

Palm groves provide sheltered and shaded aspects for both intercrop and livestock. Chickens (for controlling pests such as rhinocerus beetle larvae), guinea pigs, geese and land tortoises (to reduce grass competition), pythons (for rat and mouse control), owls (the best rodent predator), bees for pollination, and all species for their manurial value and other possible beneficial additions to the palm/crop/interplant complex, give complex yields as a by–product. Pigs are ideal scavengers in tree crops below palms and fruit. Chickens and ducks are especially valuable in weed control in pineapple, ginger and taro, and will control comfrey and *Tradescantia* if needed (the latter plants also control grasses if planted as part of a weed barrier).

Perhaps the main function of animal species in the tropics is to "recycle" plant wastes and to help control the rampant growth of ground cover. The usual domestic species, often penned, are pigs, chickens, geese, guinea pigs, rabbits, pigeons, and milking goats, cattle, or buffalo. Horses and bullocks or oxen perform draught animal functions.

Moreover, useful endemic animal species (and especially island species of restricted natural range) need to be more widely examined for their particular uses, and selected for their functions in a wider set of trials out of their normal range.

In the established tropical system, geese control pond-edge grasses, and wallaby or small grazers keep forest clearings and paths open; both are encouraged by feeding-out bran or pollard in the areas to be clipped.

Where no foxes or pythons threaten poultry, flocks of guinea fowl and hens, ducks and bantams perform invaluable pest-control and manurial/scavenging roles. Where predators are a problem, special housing, or pigeons in safe elevated roosts, may be the only way to keep fowl. The effects of electric fences in tropical areas, if not within forest edges, are often nullified by the rank growth of coarse grasses, and become inoperative for repelling python, pig, bandicoots and foxes. For this reason, fence lines must be planted with a dense perennial ground carpet of low herbaceous plants to exclude grasses, or overshaded by tree canopies.

10.10

THEMES ON A COCONUT OR PALM-DOMINANT POLYCULTURE

There are many considerations to bring to the planning of a coconut or palm-dominant polyculture; they can dealt with in the following themes:

- Structure and zoning.
- Species selection.
- Patterning.
- Economics.
- Re-working old plantations.
- The effects of plantation monoculture.

STRUCTURE

Any humid tropical polyculture that duplicates or imitates the normal structure of a tropical forest is likely to succeed. The structure of the system refers to the final cross-sectional appearance of any polyculture. Near large markets, or mass transport systems, it is quite feasible to introduce large tree species into the palm system, and to use the fruits and nuts as a supplementary market crop. Around villages, a far more complex and species-rich approach is needed, with fuel, fodder, structural materials and basic foods, oils, and medicinals in a complex intercrop. Remote from settlement or market, some livestock ranging (pigs, cattle) can be contemplated, with the intercrop selected to assist animals on range over dry periods, as ground forage, or as a drop from fodder trees such as figs, breadfruit, papaya, or *Inga edulis*.

Proximity to village or settlement decides species complexity and (by implication), structure, in that labour-intensive systems are best placed close to the village. Zoning out, we might place:

- Productive trees in palms (total species: 6–12) **Figure 10.31.A**.
- Palms within crop and avenue cropping between palms (total species: 30–35) **Figure 10.31.B**.
- Animal forage and free range in palms (total species: 8–20) **Figure 10.31.C**.
- Village garden and trellis, roof crop, greens (total species: 100–150) **Figure 10.31.D**.
- Fuel-wood in dwarf palm (total species: 3–4) **Figure 10.31.E**.
- Forest and tree reserves.

It is in and around the village that small livestock, fungi culture, padi crop and terrace is appropriate.

CRITERIA FOR SPECIES SELECTION

For any one site a selection of species that go with a palm polyculture has to be made. Some criteria are:

<u>In village</u>: A mosaic of the full range of food, craft, and medicinals is needed. Special intensive crop such as fungi, padi, and even algae can be planned. Experimental plots can be located here.

<u>In palms</u>, species are selected according to a general zoning/use-plan. It is helpful if:

- Species are suited to soils. A mosaic approach is indicated based on soil drainage and nutrient status. If the site is complex, then so should be the main crop.
- Species are locally acceptable, or are very similar to local types. New introductions need trials and instruction as to processing.
- Species chosen have a wide potential for processing. Coconuts have hundreds of known products or uses; this gives market flexibility.
- Species do not become rampant (unless they are controlled by livestock or cultivation).
- There is good information, some varietal types, and assured yield or low management input for the species used.
- Species are compatible, such as those listed herein.
- Species serve a present and future essential use (as thatch, fuels, oils, dry-stored food).

<u>Considerations for Varietal Selection</u>

For coconuts, and many other species (guava, yam, taro, banana, papaya) there are dozens of varieties developed for quite specific sites, soils, microclimates, or uses. There are coconut palms ideally suited to oil production, while others produce very fine quality cup copra for temple use, and others are ideal for shredded coconut, coconut milk, fresh nut markets, and so on.

There are dwarf, medium-height and tall varieties.

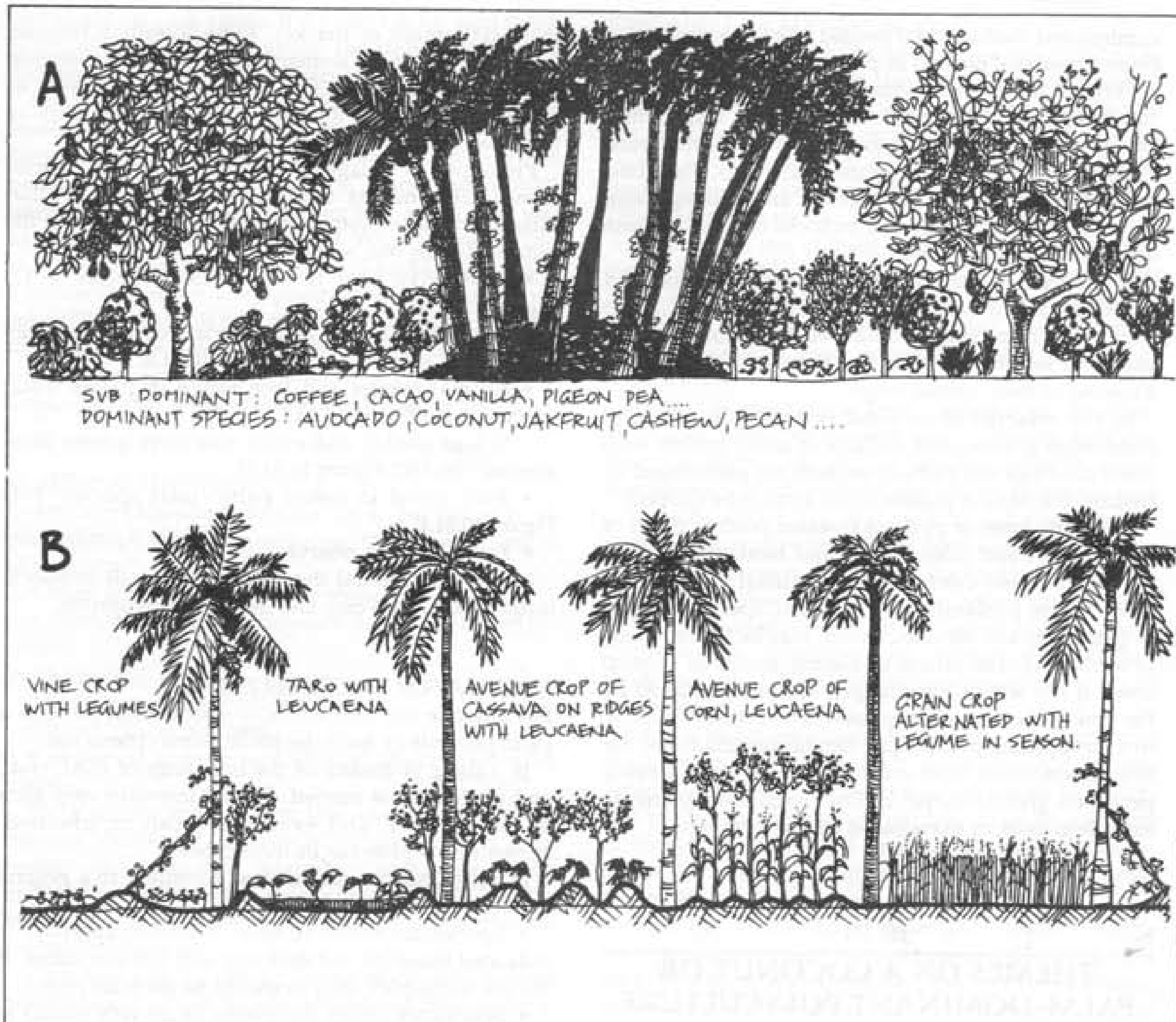
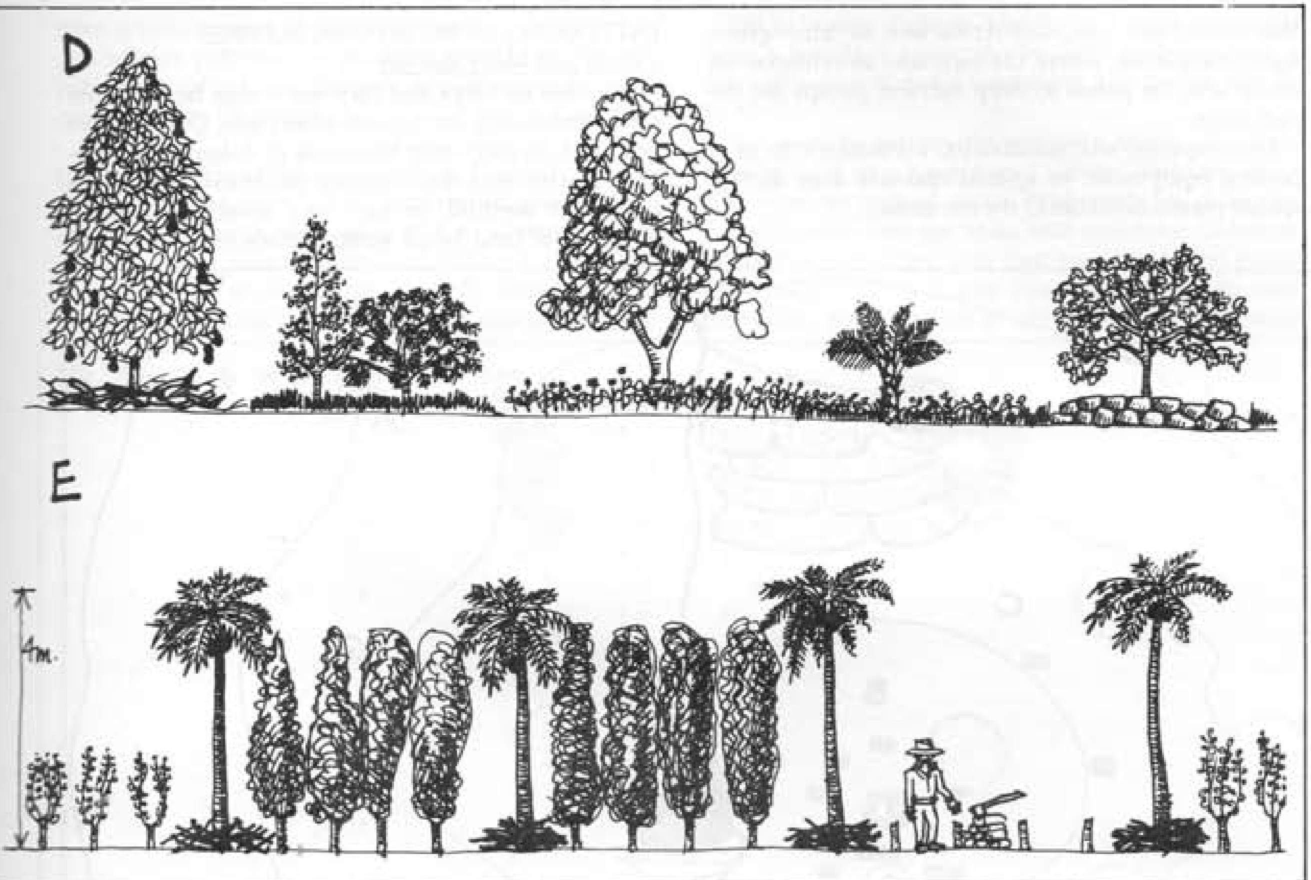


FIGURE 10.31
A–E STRUCTURAL VARIATION IN PALM POLYCULTURE.
A - Palms–fruit layout; B - Palm row crop; C - Palm–pig forage or cattle forage; D - grassland evolution; E - Fuelwood plus palms. All can be zoned around a village.



The former are ideal for village surrounds, especially in windy areas (where there are dozens of deaths each year from falling coconuts). Dwarf varieties (Philippine, Samoan) are easily accessible, have large nuts, good eating characeristics, and will not damage people or buildings if the nuts fall. Pest resistance and soil type must also influence cultivar selection.

In older plantation areas, selected and well-tested local species will be available. For areas with no plantation history, it is perhaps wise to build up a small arboretum of many varieties, and select a range of cultivars suited to the end-product aims. In every country, the cooperation of local agricultural authorities, and their assistance with varietal selection will be needed. Once a nursery is established (either as large containers or open bed planting, later as field plantings where rainfall permits), the site planning can go forward, but every plantation needs a mulched, shaded nursery, no matter how modest. Shade is most cheaply provided by light-foliaged legumes at wide spacing (e.g. *Acacia, Albizzia*).

Natural Variation

As almost all coconuts must be seed-grown, we can expect a variation in all crop characteristics, subject to later selection, culling, and new selections for site. Even if we grow from root tips in tissue culture, meristem and single-cell mutations are very high. In seed-grown crop, we might expect about one in twenty trees to show some very different characteristics, and of these perhaps one-third will be favourable for site, giving a limited set of new characteristics for selection.

Thus, it is unlikely that seed-grown *or* culture-grown palm plantation will demonstrate a very uniform genetic resource, and this will later lead us to "cull and select" options in management. This indicates a need for initial over-planting to allow for a 2-4% cull within the first 7 years (when we can make a fair estimate of vigour, nut production, bearing, and pest resistance) and another 2-4% cull in years 7-14, when the tree is mature. Final culling (14-60 years) should be in the nature of a replant and renewal process. Culling and replanting in palm crop can be a continuous process, so that plantation vigour (and overall design) is updated.

Species Suited to Co-processing

In special planation intended for (e.g.) ethanol or biogas fuel production, the same ferment and distillation equipment will serve a complex of crops that can form a "special use" polyculture.

In alcohol-oriented (fuel) palm crop, interplant of cane sugar, century plant (*Agave*), beet or sorghum sugar may add to the total sugar crop and suit the processing or distillation unit, while oil palms may be interplanted with mustards, sunflower, rapeseed, etc. to take advantage of oil press equipment and to increase honey production for bees, which themselves increase oilseed crop.

Similarly, wetlands suit many swamp palms (*Nypa*, *Maurantia*), taro, rice, and *Azolla* fern or blue-green algae complexes, where the fern acts as nitrogenous mulch and the palms as deep nutrient pumps for the padi crops.

Thus, special site conditions, investment in processing equipment, or special end-use may dictate special plant assemblies in the site mosaic.

PATTERNING OF PALM POLYCULTURES

Pattern and Water Run-off

Many sites on clays and clay-loam soils benefit from earth-sculpturing for run-off absorption. On extensive sites, and on clays over limestone or dolomite, absorption swales may be the only practical broadscale irrigation method. In fact, any levelling or subterracing of land helps water infiltration. Palms and

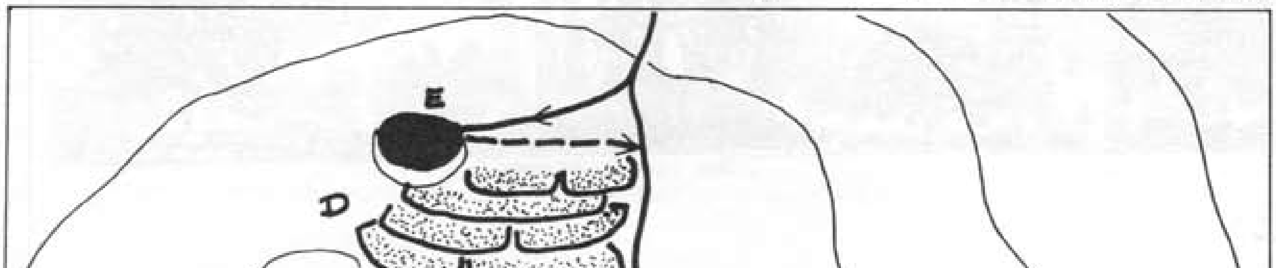
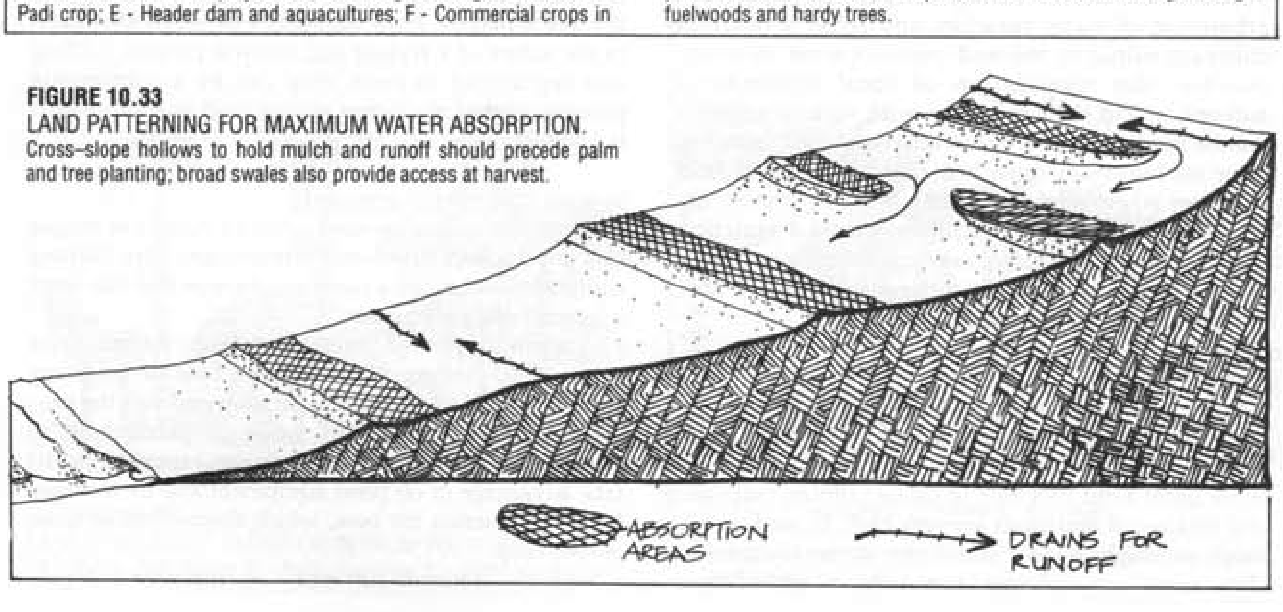


FIGURE 10.32
APPROPRIATE VILLAGE ZONATION.
A - livestock; B - Palm polyculture; C - Forage for larger animals; D - Padi crop; E - Header dam and aquacultures; F - Commercial crops in palm; G1–G3 - Reduction in species and increase in wild gathering - fuelwoods and hardy trees.

FIGURE 10.33
LAND PATTERNING FOR MAXIMUM WATER ABSORPTION.
Cross-slope hollows to hold mulch and runoff should precede palm and tree planting; broad swales also provide access at harvest.



trees appreciate ground water reserves.

A hillside patterned as per **Figure 10.33** suits clump plantings of palms. Swales are illustrated and exemplified in Chapter 9.

Planting Patterns of Palms (Clumps vs Grids)

Without altering too much the appearance, spacing, and amount of coconuts, **Figures 10.34.A–C** illustrate some of the possible plantation layouts. While **A** and **B** are "normal", **C** arises from several independent observations I have made on densely-planted coconut

Ten to twelve coconuts planted in a circle, and each only a few feet apart, do in fact quickly adopt a divergent growth habit something like that in **Figure 10.35**.

Not only do nut counts compare favourably with trees planted on a square grid pattern, and nuts drop cleanly to the ground, but a third (probably more important) factor emerges, to do with mulching. Coconuts in plantation mulched with their own fronds and husks show better growth and bearing, but in normal plantation, husks are left at one tree in 10–30, because

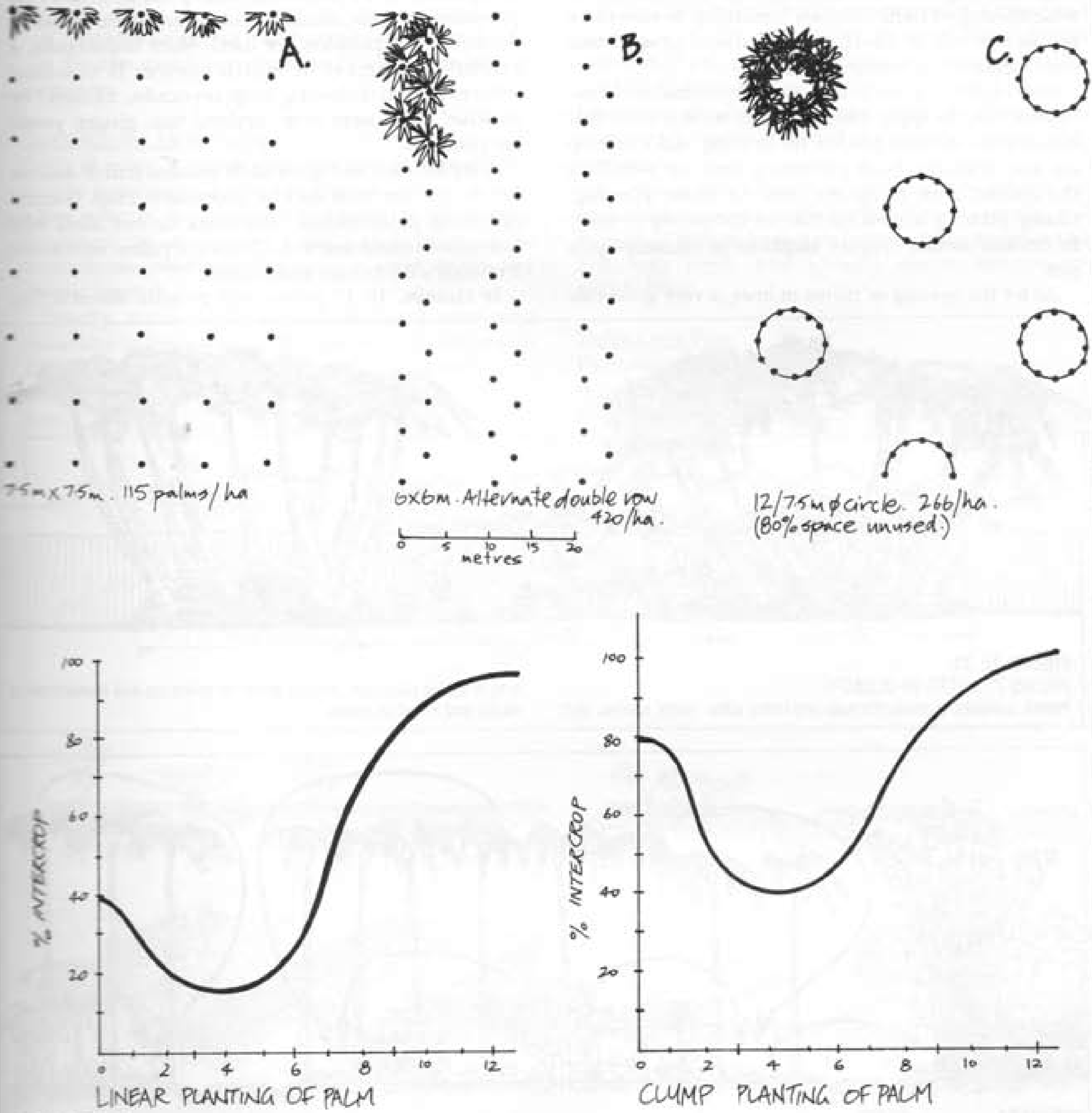


FIGURE 10.34
COMPARISON OF LINEAR AND CLUMP LAYOUTS.
Schematic of intercrop yields over years 1–12; clump palm layout allows more, and earlier, crop yields. Plan shows how various palm layouts frees up ground space, enables easier access, easier mulching and irrigation.

the labour of first gathering and then distributing the mulch is too great. However, with the circle clumps, it is easy to both gather and husk the coconuts in one place, and thus mulch the base of *all* trees, conserving water and returning nutrients to every tree. A little care in turning husks face-down prevents mosquito breeding in these mulch heaps.

Any other nutrient (manure, blood and bone) is equally easily applied to clumps. Clumps also form more suitable trellis for vanilla, black pepper, and other vine crop, are very economical for watering, and leave a large area of ground free (although lightly shaded). The wide spacing of circles enables replanting to take place in discrete sets of 10–12 palms without gross linear disturbance to the system as a whole.

Although I originally saw such clumping as a convenient way to apply mulch, it later became clear that broad areas of clear ground for grazing and intercrop are also available. Such patterning frees up to 60% of the ground area, as against 30% for linear planting. Clump planting is ideal for run-off harvesting of water in circular swales (**Figure 10.33**) or in coconut-circle pits.

As for the spacing of palms in lines, a very good rule is to space at twice the frond length for that site plus two feet. This allows full crown development without abrasion damage to the fronds from wind-sway. Intercrop spacing is as usual: cacao 2 x 3 m, banana 3 x 3 m, cassava 1 x 1 m, velvet beans 0.5 x 0.5 m, maize 1 x 0.5 m in rows, citrus 9 x 9 m and so on (local agricultural people can advise). Coconuts on new sites are normally 6 x 6 m.

Access and Mulch Provision

Sensible roading or grassed access ways are necessary for gathering or handling heavy crop, and some provision for these must be made even where horses or donkeys with panniers are used. More importantly, a careful assessment of mulch sources is essential wherever mulch-loving crop (avocado, banana) or mulched short-term crop (dryland taro, ginger, yams) are planned.

A layout such as **Figure 10.36** ensures mulch sources for the system itself and for short-term crop. Natural fall from palm fronds, and husk or nut shell will line-mulch about one in 8–12 rows of palms with about 2 m wide x 0.5 m high mulch beds.

In clumps, 10–12 palms will provide about 0.5 m

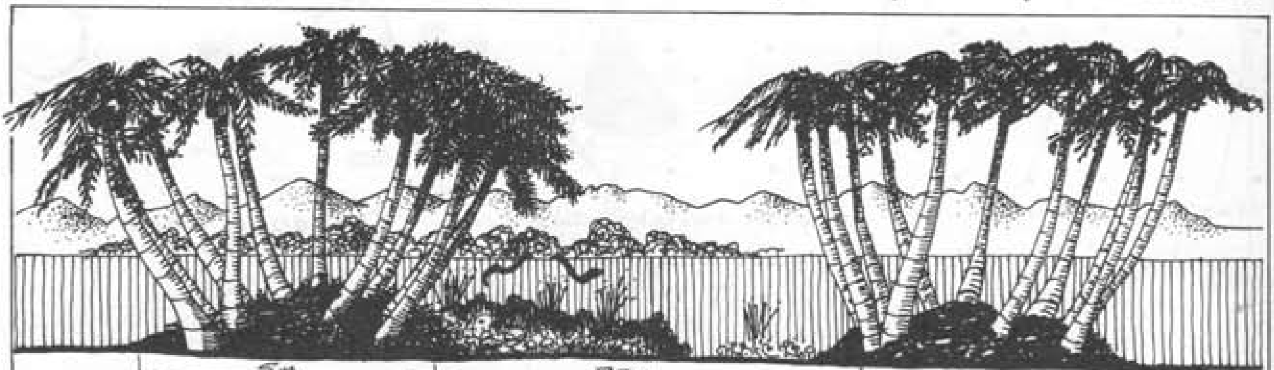


FIGURE 10.35
PALMS PLANTED IN CLUMPS.
Palms, bananas, macadamia nuts and many other useful species yield well in clump plantings, freeing space for intercrop and concentrating mulch and irrigation needs.

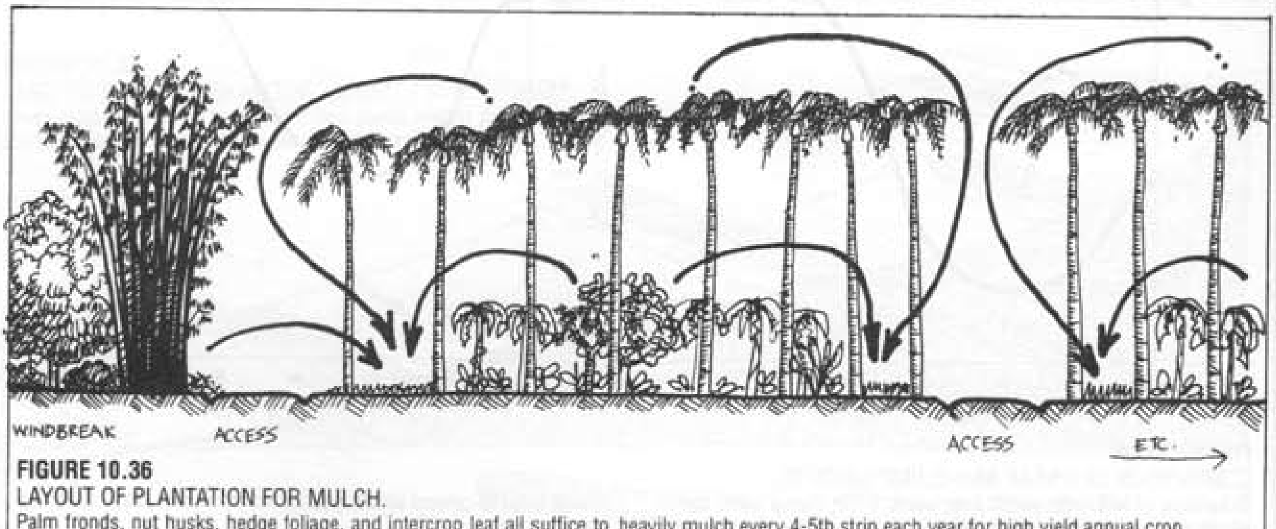


FIGURE 10.36
LAYOUT OF PLANTATION FOR MULCH.
Palm fronds, nut husks, hedge foliage, and intercrop leaf all suffice to heavily mulch every 4-5th strip each year for high yield annual crop.

deep of mulch for the inner circle of mulch. This is easier to gather and keep in place in windy areas. The addition of bananas, especially with avocado, has become standard in many planations, as the banana plants at harvest (with root mass) provide about 25 t/ha of organic matter, a key resource for a healthy fruit and palm crop (Penn, J., *New Scientist* 20 May '85). Small tree legumes (*Cassia, Calliandra, Leucaena*) also help. Bananas in legume crop may be regarded as "pioneer" mulch in grassland reclamation.

The layout in **Figure 10.36**:

- Reduces the labour of harvest by providing regular access.
- Provides sources of mulch for short-term crop.
- Enables mulch accumulation by long-term crop as interplant.

Earth Shaping for Intercrop

Earth shaping is worthwhile for several reasons, not only to assist water infiltration and run-off, but to give a free root run, to retain mulch in wind, to effect better drainage in over-wet areas, and to provide microclimate benefits with respect to wind shelter and ground warmth.

Briefly, earth MOUNDING for root crop and cucurbits is beneficial in humid tropics, and earth TRENCHING is best in dry tropics. Earthworking is discussed in Chapter 9, but some relevant data is given here.

RIDGES. Ridges of 0.5 x 1 m increase yields in cassava, sweet potato, potato, and yam crop. Mulch and green crop can be grown between the ridges. Pineapple and ginger also prefer ridges in wet areas. In **Figure 10.37**, *Leucaena* intercrop for mulch is on mounds, while maize and green mulch (beans) occupy hollows. Ridges permit deep mulching for low crop such as pineapple, the mulch being applied between ridges.

MOUNDS and volcano-shaped mounds with hollow centres are good cucurbit sites if enriched with manures. A stone or two helps heat the earth to germination temperature for cucurbit and melon crop.

FURROWS assist mulch retention for ginger and pineapple in dry areas. They are best covered with mulch, and will carry subsurface water seepage lines.

BASINS, even shallow basins, aid dryland taro and banana, or patches of Chinese water chestnut. Soil is more easily saturated, and deep mulch assists this process.

BOXES of palm trunks are ideal mulch-holders for yams, banana, and vanilla orchid, vines generally, and borders of beds in home gardens. Such log boxes can be 1-3 logs high, and greatly assist weeding if mulch-filled.

Yields Over Time

Plantation can be cropped with short-term grains for a season or two, but by years 2-4, the palm fronds (of linear plantings, not so much of clumps) cause mech-

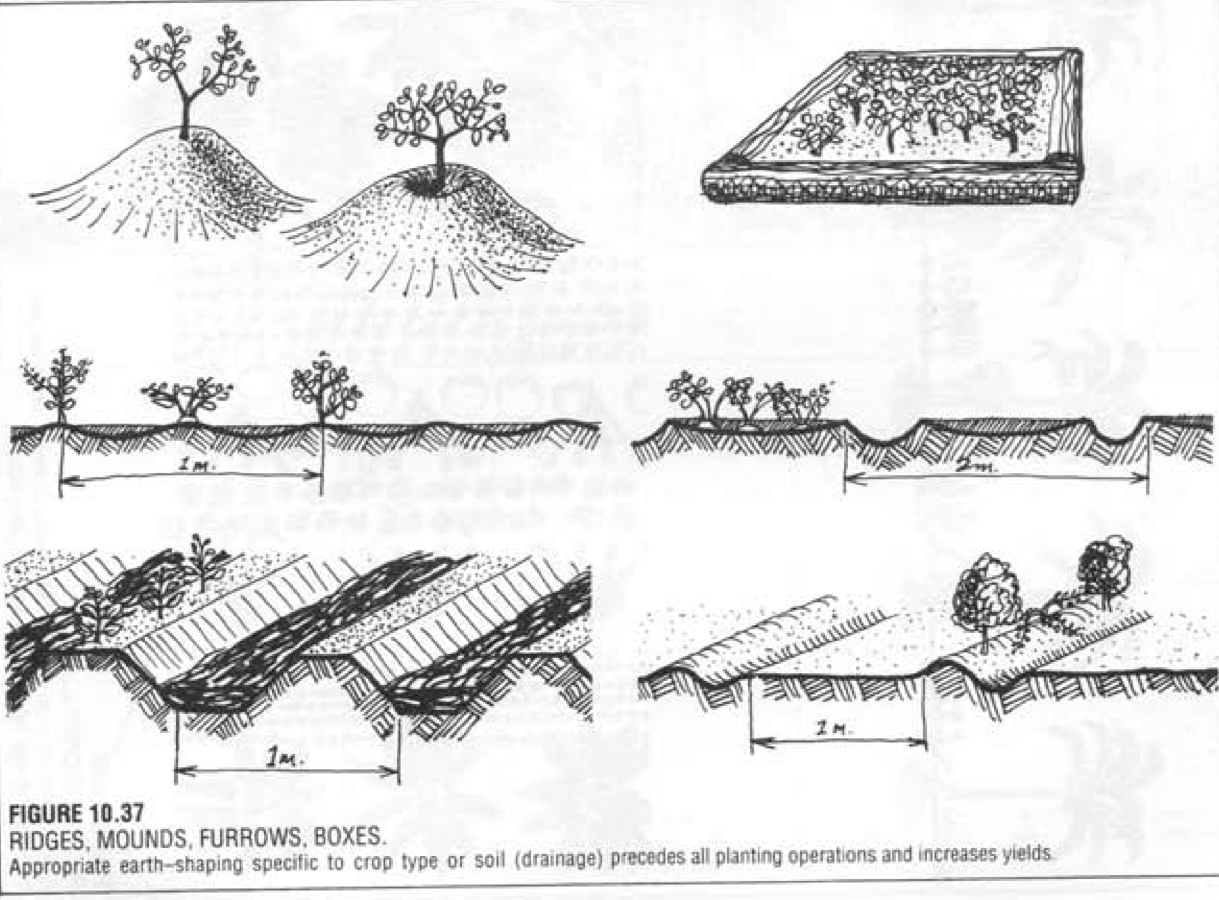


FIGURE 10.37
RIDGES, MOUNDS, FURROWS, BOXES.
Appropriate earth-shaping specific to crop type or soil (drainage) precedes all planting operations and increases yields.

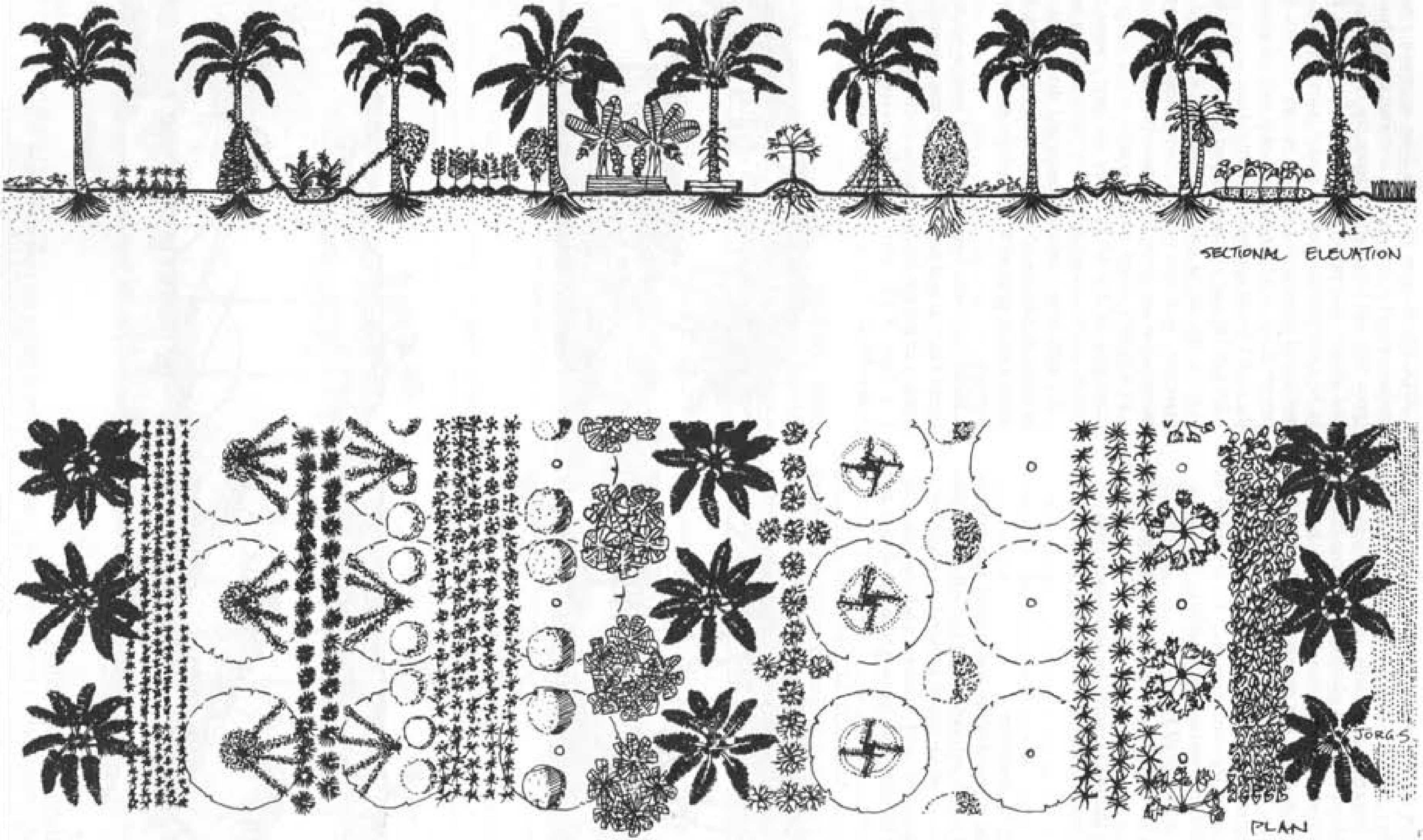


FIGURE 10.38
PALM INTERCROP .
A wide variety of crop, and accessory earth, or trellis, structures can be integrated with palms after years 4–7. [Jörg Schultz].

anical damage and obscure the ground. After years 4–6, a stem forms, and from 6–14 years, complex perennial intercrop (not short-term grains) can be placed in linear systems. In clump systems, the early ground effect is less marked.

ECONOMICS

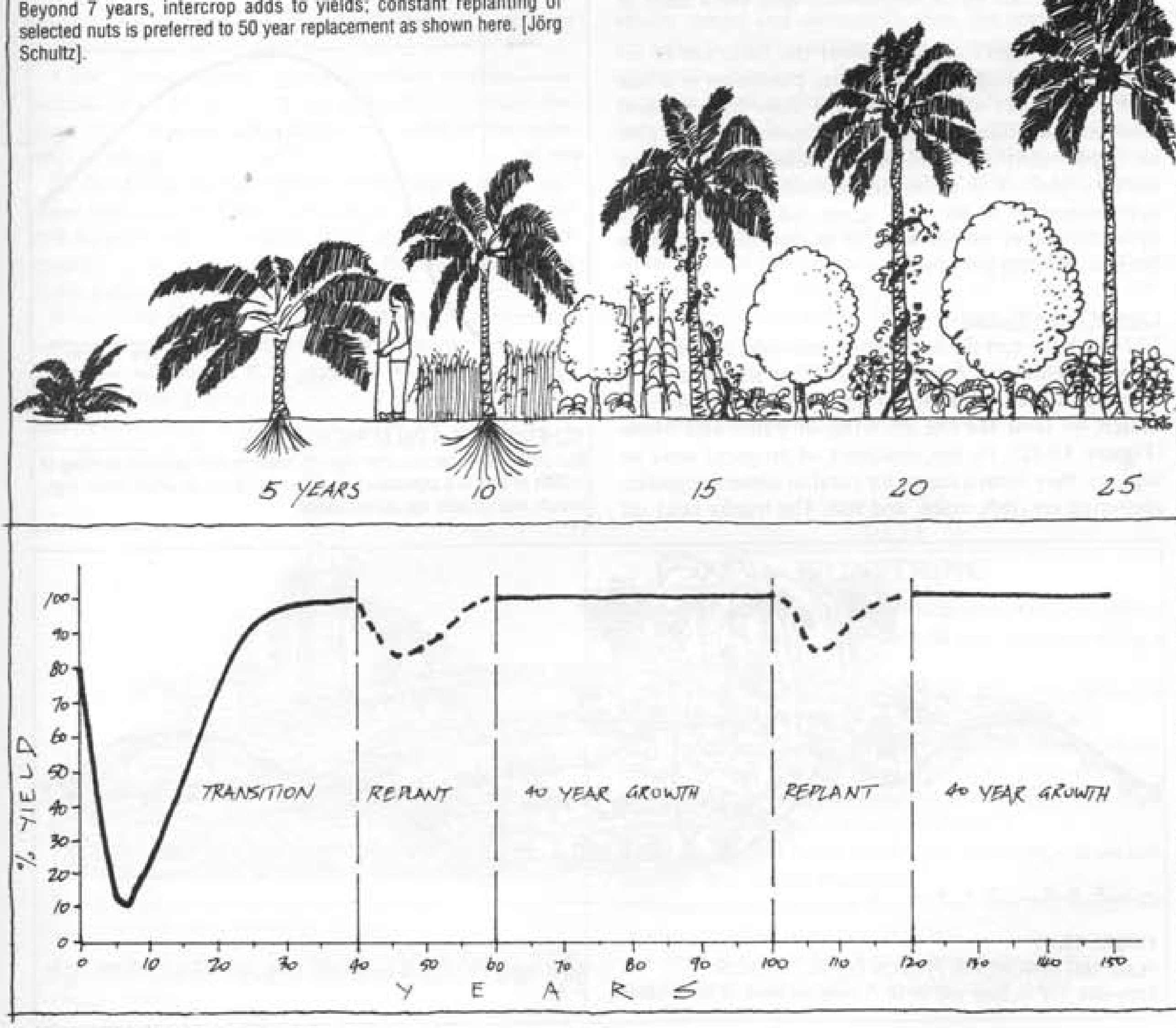
Nair (1975) gives convincing economic analyses for coconut, showing a 50% increase in yield for irrigation alone and a trebling of the yield for complex intercrop of two or more species, effectively doubling the cash return to the grower on the same area. Costs of irrigation and intercrop (plant or animal) never exceed returns if care is taken to select beneficial plant and animal species for available soil, water supply, and climate. Often, the cheapest irrigation system is to pattern the ground to hold wet-season run-off for tree crop use in dry seasons.

On Nair's anlaysis, where 1 unit = 4 rupees, the net income from coconut was as **Table 10.2**. Adding three species and increasing net yield by 3–9 times increases costs by 3.1 times. This is a clear implication for smallholders that much less area, polycultured, would give as much return (3 to 8 times) for *far less expense* (as expense is also a function of expanded area under crop). Irrigation of any sort is obviously a key factor. There would be a point, however, where more species added, even if very carefully selected, would push labour, harvest, and control costs past sensible limits, as per the schematic in **Figure 10.40**. So it is also clear that a complex polyculture must be managed by many more people if expanded to a wider scale.

RE-WORKING OLD PLANTATIONS

People who inherit or buy old stands of coconut or other palm crop need to undertake clearing and

FIGURE 10.39
YIELDS OVER TIME.
Beyond 7 years, intercrop adds to yields; constant replanting of selected nuts is preferred to 50 year replacement as shown here. [Jörg Schultz].



replanting programmes for renewal if the stands are 60+ years of age. This is an ideal time to re-assess the potential for intercrop, to assess local processing potential, and to use the trunks, fronds, sugars, and palm heart products of the over-mature palms for mulch, food, and structural material. If hurricanes have stripped the old crop, it is also timely to assess the placement of windbreak for future plantation, and to place *Casuarina*, *Acacia*, *Albizzia*, bamboo, or tough *Prosopis* species to afford greater shelter and to fix nutrient in the crop, or to provide forage for grazers such as pigs, cattle, tortoise, or game birds (turkey, geese).

The clearing of old trees should be carefully planned to give a maximum return and to correct placements in older plantations. As it may take 8–15 years to rework a neglected, old plantation, the process can be staged and tuned as trial systems. In many areas, the old palms are tapped for sugar before removal, and the palm hearts eaten or sold as "millionaire's salad" (although palms planted specifically as young heart crop have a very good yield, can be close-planted, and are a crop in themselves).

Good managers may be about the business of replacing, replanting, or re-grouping plantation at a rate of 4% or so per annum, giving a slow but constant renewal and culling as needed. The new trees also give an opportunity for field-testing selections from the nursery beds. It is generally agreed that coconut is over-mature in 40–80 years, when nut yield falls from optimum 45 per tree or so to 15 or less. Excellent trees bear 60–100 nuts per year.

Uses of Palm Trunks

The trunks of coconut are a good resource; not only do they provide an excellent building material, but (stacked in open box fashion) they make baskets to hold mulch on land for the growing of yams and vines (**Figure 10.42**). In the shallows of tropical seas or lagoons, they form a frame for coral to cement together, sheltering crayfish, crabs, and fish. The trunks hold silt and sand in reclaiming new lagoon areas, or in creating stable planting ledges in "hurricane garden" hollows cut into coral sands, on the sides of gleyed or plastic-lined surface ponds on islands, or as an aid in retaining bank stability and plant establishment on slopes.

Palm trunks can also be used to create planting benches on pits on coral islands. Pit base: taro, mint, parsley, kangkong. Sides: cassava, papaya, yam, banana. Spoil: sweet potato (mulched). **Figure 10.41**.

THE EFFECTS OF PLANTATION MONOCULTURE

Plantation crop in the tropics may bring with it all the evils of monoculture, and especially those of poisonous sprays, which not only affect the workers themselves but infect all streams and eventually town water. These sprays drift over adjacent properties, making livestock unsaleable, and poison the landscape generally.

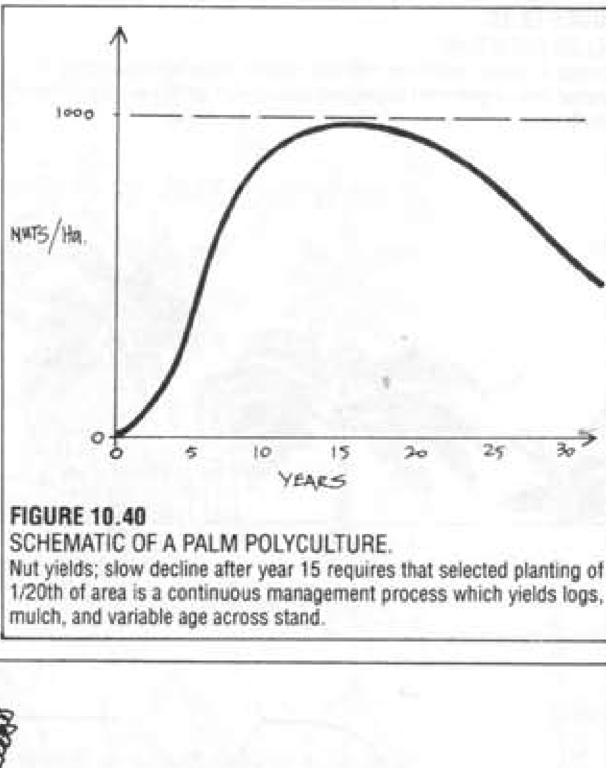


FIGURE 10.40
SCHEMATIC OF A PALM POLYCULTURE.
Nut yields; slow decline after year 15 requires that selected planting of 1/20th of area is a continuous management process which yields logs, mulch, and variable age across stand.

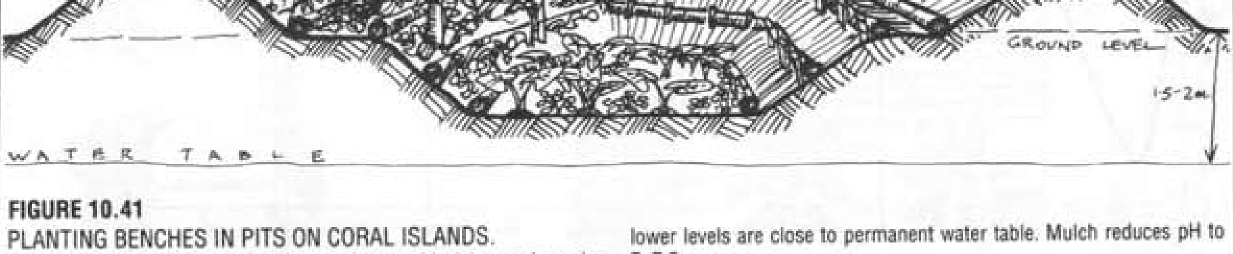


FIGURE 10.41
PLANTING BENCHES IN PITS ON CORAL ISLANDS.
Grow-pits 1–2 m deep and 8–12 m wide are ideal in coral sands; lower levels are close to permanent water table. Mulch reduces pH to 7–7.5.

Plantations almost invariably erode the landscape, pollute rivers, estuaries, and corals with silt and sprays, and exhaust soils. They centralise power and corrupt local politics, often funding repressive politicians, Their products are of low nutrition, and contain high levels of residual chemicals. Perhaps worst of all, plantations almost always displace local self-reliant crop, and replace it with "company store" dependency.

Cures are available. Firstly, plantations can be locally managed by worker cooperatives, as in some Sri Lankan tea plots. Here, at least, the workers have a say in and profit from their labour. This does not necessarily alter many of the ecological factors, however.

Secondly, plantations need not exist, as the same area of crop can be produced by smallholders, and processed centrally. This is a further improvement, as quality can be rewarded and good ecology instituted. Such an approach needs shared research, market, and processing systems. Thirdly, the plantation itself can adopt two reformatory practices:

- Good ecological management through the use of polyculture systems, soil building, organic fertilisers and biological control of pests.
- The "commonwork" approach, where workers lease secondary or tertiary crop in, around, and under the main crop, or lease rights to the processing of the main crop residues.

Modern analyses (computer modelling of intercrop) show that intercrop and polyculture raise employment and income, and plantation itself should be designed specifically to allow intercropping throughout the life of the palm.

It is quite feasible for people to extend specific successful crop mixes from their home gardens to more extensive situations, thus giving a surplus for trade. Money is then gained as a result of extending a stable and tested polyculture rather than by imposing a monoculture on an unsympathetic and fragile landscape. No landscape or soil can maintain long-continued monoculture production of crop, as even tree crop is susceptible to disease in this situation.

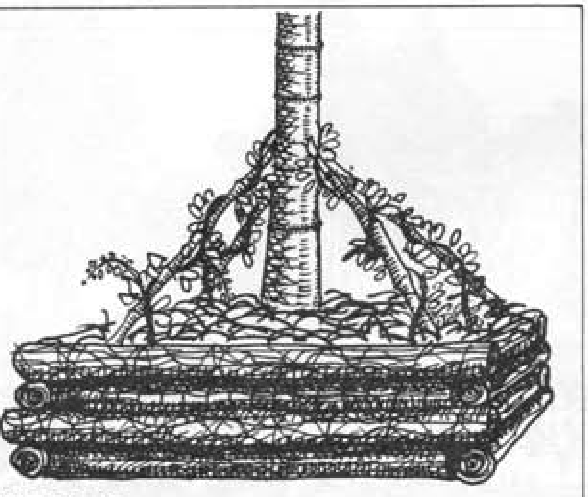


FIGURE 10.42
MULCH BOXES MADE OF PALM TRUNKS.
Palm– or log–surrounded areas filled with mulch are ideal for vanilla, yams, beans, cucurbits in sandy or alkaline soils; also on a larger scale for potato, tomato.

TABLE 10.2
ECONOMICS OF PALM AND INTERCROP (AFTER NAIR).

PLANTINGS	NET (Units/ha)	EXPENSES (Units/ha)
Coconut only (under rainfall)	1,000	600
Coconut only (irrigated)	1,512	817
Coconut and cacao	3,122	1,300
Coconut, cacao, black pepper,and pineapple	3,882	1,880

The approach of extending small and successful trials is basic to success. Broadscale trials have unstable effects (social and ecological) from the beginning, and success is rarely achieved as a result of such an approach. However, it must also be recognised that complex small systems may work well simply because they are close by, and many such systems cannot be scaled up to large acreages as a totality. Size itself creates new factors of cost, control, market, and labour requirements.

Plantation and monocrop have the undeniable advantages of ease of harvest and predictability, neither of which are necessarily the best criteria for human-centred benefits. Malnutrition and low socio-economic status are common factors in the human populations of the wet tropics, and criteria such as full nutrition and enhanced self-reliance are where we should be concentrating for the tropics.

10.11
PIONEERING

If we are going to pioneer in the tropics, the only ethical conditions in which we would contemplate such a process is to rehabilitate:

1. Grasslands developed by burning/grazing sequences and monsoon grasslands.
2. Semi-forested clearings and old monoculture plantations of, e.g. sugarcane, banana, pine, eucalypt, pineapple. (We will suppose some "weed" invasion by *Lantana*, tobacco bush, vines, or shrubs.)
3. Logged and burnt forest with reject logs, branches, stumps, and weedy regrowth.

These are some typical conditions. The end results we would envisage would range from:

- Terrace culture and water absorption systems.
- Extensive aquaculture or substantial dams.
- Polycultural forests.

• Managed forestry or rehabilitative forestry for perpetual yields.

Or, more probably, we would plan for all of these in appropriate combinations for site.

TROPICAL GRASSLANDS

The management of deforested grassland areas is the main problem of the wet-dry tropics: soil erosion, rank grasses in the wet, and inflammable or low-nutrition feed in drought result from burning and over-grazing. Once deforested, the pastures are open to summer winds, and the nutrient cycle of trees/grass/ browsing is broken. Fire, often out of control, only accelerates the process. Although there are very few trees which can survive in tropical grasslands, it is essential to re-establish tree legumes.

Some vigorous grassland cover crop legumes (*Desmodium, Suratro*) will help reduce the grasses and eventually lay down a mulch. Under trees, a short-stemmed *Desmodium* will defeat the grasses, but it is then essential to be able to supply dry-season water, as the legume also competes with the young trees for moisture. Some fast-growing leguminous trees (*Albizzia, Acacia, Inga, Leucaena*) will quickly establish, and can be grown in the shelter of banna grass or elephant grass (*Pennisetum*). If these grow vigorously, they also provide green mulch.

Heavy cattle browsing is a major cause of pasture deterioration and soil loss. Their extensive grazing is probably the most common destructive use of tropical lands. The first step is therefore to relieve the land of the weight of too many cattle. No nation, nor the globe, can support destructive grazing agriculture on the agribusiness/cowboy/pyromaniac model so general in tropical countries, in America, and wherever "cheap" beef is produced. The long term cost makes such systems uneconomic in any terms.

A positive approach is to re-establish either a multi-species system ecology (trees and a variety of browsers), or to intensify cattle rearing. Cliff Adam, Chief Research Officer at Grand Anse, Mahe, in the Seychelles has grown *Pennisetum atropurpureum* (7 parts) plus *leucaena leucocephala*—the low-mimosin type available in Australia—(1 part), and may add the Bocking strain of comfrey. This "pasture", cut and fed to cows, supports seven milk cows to the acre. All manure and washings from stable/dairy are returned to the irrigated field. Imported artificial manures have been reduced to one-tenth, and he hopes to further reduce this import by building soil. Meanwhile, in the same climate in Australia, one cow per square mile is enough to lay waste to the land.

A friend who bought a degraded cattle property north of the Daintree River (Queensland, Australia) gathers a load of coconut from the beaches, and (travelling the ridges of old fields just before the wet season) throws dozens of coconuts at intervals into the stream-lines and gullies. About 4% take root and grow into sheltered and pioneering palms. Not far south of there, another innovator rolls down the monsoon grasses as they begin to die off in the dry season, and broadcasts tall-stalk rye and field legumes (Fava, *Dolichos, Vigna*) into the thick resulting mulch. Enough moisture persists over the dry winter season to grow these crops; after harvest, the monsoon grasses regrow for next year's rye crop.

This clever use of seasons and growth is possible for the establishment of many species, some of which become permanent and grass-defeating pioneers for later evolutions. Consolidation of the area for regenerative forestry, however, proceeds more surely as a scattered set of pioneer tree and herbaceous nucleii; that is, the steady establishment of CLUMPED pioneer trees in open grassland. This is a "natural" process which duplicates the seeding of grasslands by fruit pigeons

FIGURE 10.43
PLANTING IN GRASSLANDS.
A dense (2 x 2 m) planting on "nucleii" of legumes, palms, shrubs, ground covers, and bulbs plus stone or stick mulch quickly shades out grasses and produces a closed canopy. [Jörg Schultz].

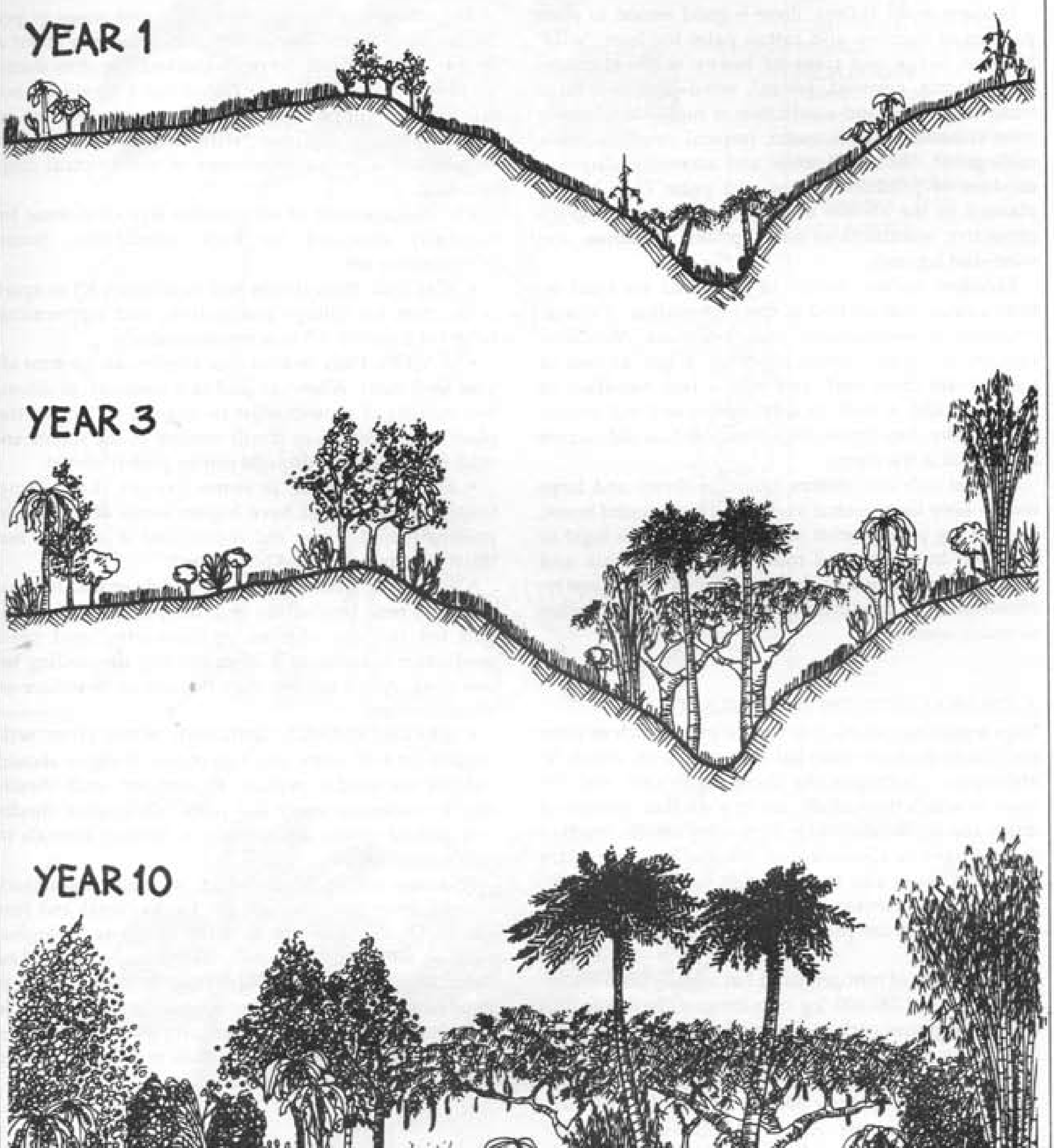


FIGURE 10.44
NUCLEUS PIONEER COPSE IN GRASSLANDS.
Dense nucleus mulched planting joins up to create self-generating forests in grasslands within 10 years.

and fructivorous birds.

In steep moist valleys, there is good reason to plant patches of bamboo and rattan palm for later "wild" harvest, large nut trees of heavy water demand (macadamia, coconut, pecan), wind-sensitive large fruits (avocado), and a selection of high-value timber trees (rosewood, teak, cedar, tropical conifers, balsa, mahogany). On more gentle and accessible slopes, a mixture of productive tree and palm crop can be planted in the shelter of pioneers, and on ridges a protective windbreak of hardy palms, *Casuarina*, and wind-fast legumes.

Excellent nucleii clumps in grassland are built up from a close-planted (1-2 m spacing) mixture of *Acacia mearnsii, A. melanoxylon, Inga, Gliricidia, Nicotiana, Casuarina, Vigna, Tagetes,* comfrey, a box or two of nasturtium (box, soil, and all), a few handfuls of fertiliser, and a visit to slash grass and tall weeds occasionally. Any stones, logs, cardboard, or old carpets help if laid in the clump.

Natural aids are stumps (plant *in* these) and large rocks—keep them central to clump. Plant around boxes, logs, or log piles (pocket soil and plant in the logs) or even old buildings and rock walls. It is within and around these pioneer nucleii that we can commence re-afforestation or productive tree crop, using our nucleii as mulch sources.

A GENERAL NOTE ON THE LEGUMES

Most legumes, and other genera of plants such as alder and *Casuarina* have mycelial root associates which fix atmospheric nitrogen. As these organisms, and the roots to which they attach, are in a constant process of death and replacement over a growing season, much of the nitrogen is also released for use by other plant species. Clover and tree legumes perform the same benefit for pastures. Such trees as the rain tree (*Samanea saman*) can preserve green grass below even in dry seasons.

The amount of nitrogen fixed has usually been under-estimated, at 75-100 kg of nitrogen/ha/year, but efficient legumes such as lucerne (alfalfa) may provide 250-500 kg of nitrogen/ha/year, and tree legumes such as *Albizzia* as much in quite poor sandy soils [Iseky, D, 1982, *Economic Botany 36(1)*]. Every part of such legumes as *Leucaena, Acacia, Albizia, Gliricidia* and *Tephrosia* may contain high nitrogen levels; one can actually smell the ammonia from the trees in rain or when the roots are crushed.

Thus, cut green material from such trees (green mulch) lightly turned into crop, water-mulched, or even as interplant, supplies much of the nitrogen for crops. It is necessary to make sure the trees are *inoculated* as seed with the correct root associates, in the nursery or in the field. Most agricultural departments can supply a list of strains of inoculants, or the inoculum itself. Many firms supply inoculum for legume and other species, or soil from nodulating trees can be washed in around newly planted trees, or mixed with potting soils.

The nitrogen is distributed around root zones as per **Figure 10.46**. Some shrubs and trees lay down about a 9-year supply, and if cut or ringbarked, the slow decay of the roots gives up nitrogen for 6 years or so. Nitrogen, if supplied artificially, quickly leaches in warm rains, so legumes, with their slow nitrogen release, *are of critical importance* in any tropical crop situation.

The management of leguminous tree crop must be carefully assessed for local conditions. Some considertions are:

- SPACING: With shrubs and small trees, 0.5 m apart is the best for foliage production, and a trimming height of from 0.5-1.5 m is recommended.
- SEASON: Only in frost-free tropics can we trim all year (4-5 cuts). Wherever cold is a seasonal problem, two months of growth must be allowed to harden the plant before winter, or it will weaken as the shoots are cold-killed. Trees in drought can be part-trimmed.
- FORAGE: There is some danger that young (coppice) shoots will have higher levels of metabolic poisons than 2-3 year old shoots, and if stock do not thrive, this factor should be assessed.
- SHELTER: Trees can be more widely spaced for root nitrogen, seed production (e.g. for poultry and bees), and for in-crop shelter, as flowering and seed production is better at 2-20 m spacing (depending on tree size). A full canopy may be needed to reduce or eliminate frost.
- REPLACEMENT: Although many trees will coppice for 4-30 years, any sign of loss of vigour should indicate the need to replant. Replant for small shrubs may be necessary every 2-3 years, while some shrubs and ground covers are annuals or become annuals in cold-season areas.

To assess total nitrogen yield, we must assess *soil nitrogen* from mycelia (say 200 kg/ha/year) and leaf and slash nitrogen/ha. In such crops as *Tephrosia*, yielding 135 t/ha in 4 cuts, leaf nitrogen should be about 20-30 kg/t, or 1,000-1,500 kg/ha/year, which is some factors higher than the root nitrogen yield. This is the whole rationale for avenue cropping and legume mulch. Phosphate and potash levels in green mulch are also satisfactory for crop production.

PIONEERING IN SECONDARY FOREST GROWTH AND LANTANA

Lantana is analagous to the rampancy of gorse and blackberry in cooler areas, and the essential process remains the same:

- Roll down, crush, or cut out contour strips.
- Plant advanced, vigorous mixes of *Acacia, Eucalyptus,* vines such as chayote, ground legumes, and local pioneer species. Manure each plant and mark small plants so they can be easily seen.
- Slash every few weeks in the wet season until the trees are above the *Lantana* canopy, and free any new natural tree seedling that comes up.

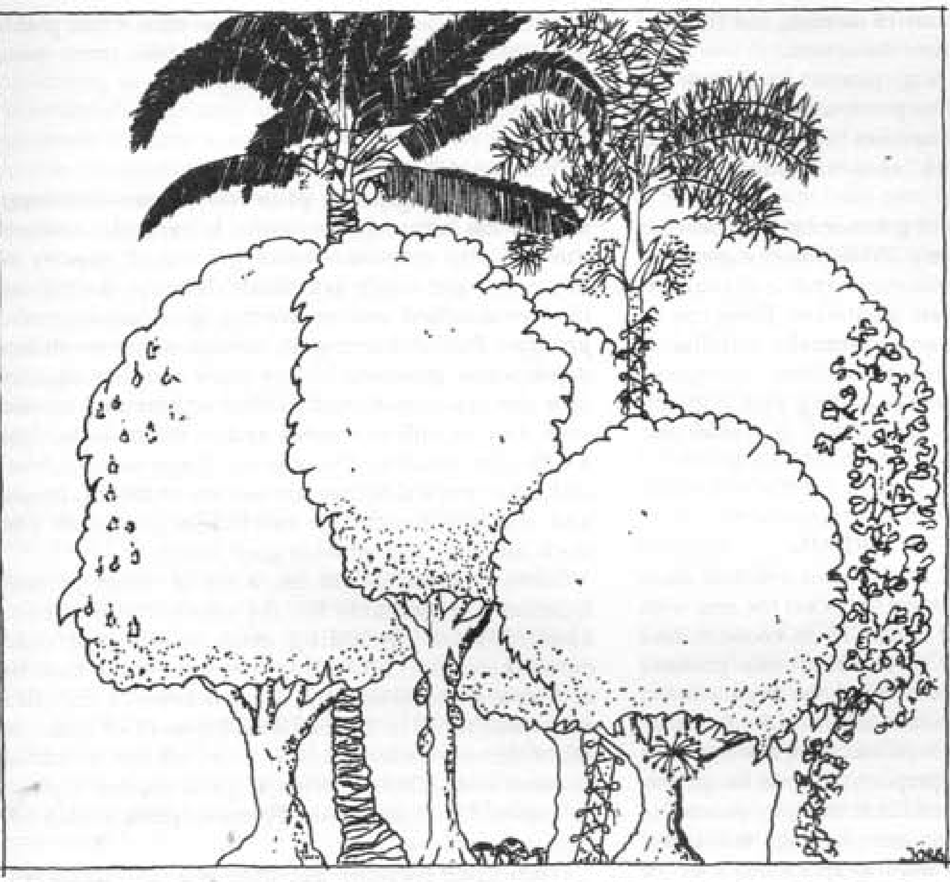
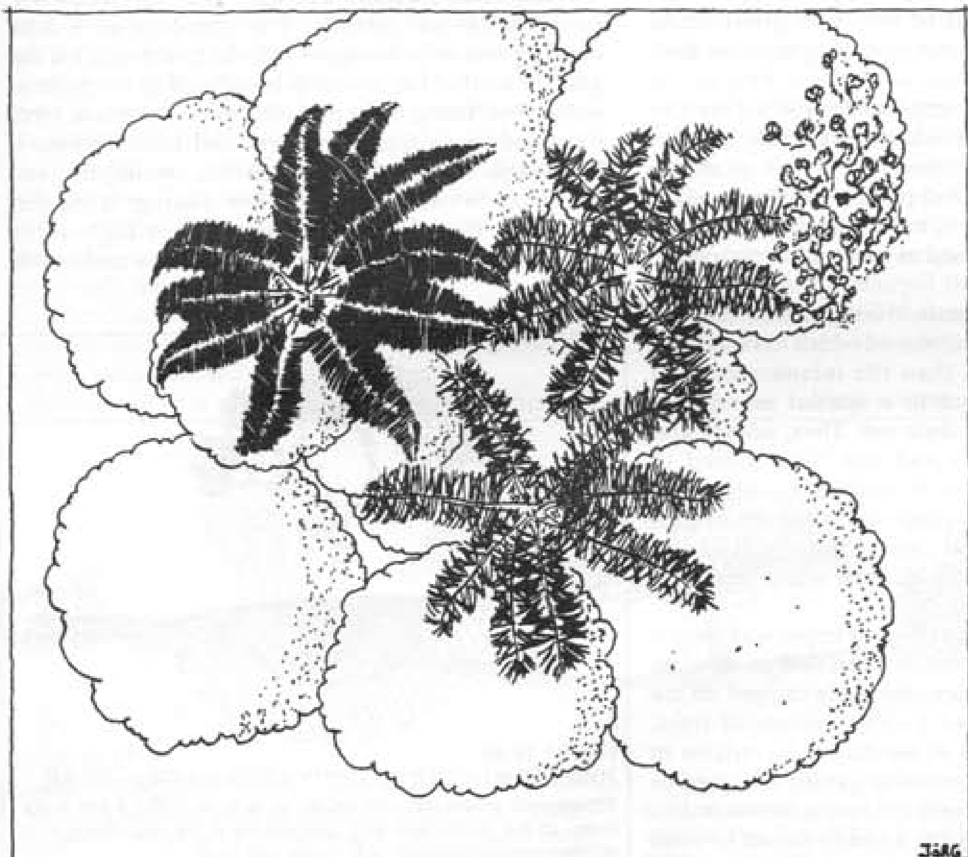


FIGURE 10.45
COMPONENTS OF THE TROPICAL FOREST TREE POLYCULTURE
Palms, lianas (vines), crown–bearers to the outside and stem–bearers inside clumps; fungi and shade species below.
A. Elevation.
[Jörg Schultz].



COMPONENTS OF THE TROPICAL FOREST TREE POLYCULTURE
B. Plan.
[Jörg Schultz].

• Do final slash at or about 18 months, and then cut or roll adjacent strips to extend the system.

• Use early pioneers (e.g. *Acacia*) as mulch for selected high-value species as previously planned.

The shading-out of *Lantana* takes from 2–6 years, and only remnant and weak shoots remain under productive forest.

In all extensive hill areas of gorse or *Lantana*, benches or roads cut on contour every 250–100 m is a great aid to regenerative forest processes and subsequent harvesting or slashing of new plantation. These can be kept mowed and cleared, and eventually stabilise as trees grow. Road borders can be of dense, evergreen, wide-crowned trees for track shading and stability. Such deep shade also keeps fences clear of grasses and weed crop.

PIONEERING ON DIFFICULT TERRAIN

On man-made and natural landslide or volcanic areas of the tropics, it is first necessary to pocket the area with soil-mulch mixtures (nut husks from coconut and macadamia are excellent to establish any pioneer species). Thereafter, species such as *Inga edulis*, *Leucaena leucocephela*, various *Acacias* (*A. mearnsii*), *Scalesia pedunculata*, *Prosopis pallida*, and like legumes (*Dolichos*, *Desmodium*) will prepare the area for palms, cacti, figs, and the more useful fruit trees, by providing shelter and mulch for subsequent plantings. It is better to plant small assemblies than to space out a lot of species on their own. It is better to plant small assemblies than to space out a lot of species on their own.

A heavy spiked roller crushes new *a'a* lava (an Hawaiian term for lava which is softish, not far removed from pumice); crushed lava is both accessible and easily rotted to soils. Soil pockets can be provided with trace elements (boron, manganese, zinc, copper, molybdenum) if not analysed as present in any specific location.

Near the sea and on islands, the night air condenses on the sea-facing side of the stones, which have a richer moss-algae-lichen flora than the inland side, and pockets of vegetation act in a similar manner to condense sea vapours for their use. Thus, islands and sea coasts will have dry and wet sides suited to different plant species. In such conditions, a ragged or spiky forest canopy, where palms and tall pines or fruit trees lift above the general canopy layer, will ensure more condensation from sea air than will a level and relatively closed canopy.

The saturated winds that sweep off tropic seas carry a heavy moisture load which is available as dew on grasslands, but is much more effectively trapped on the myriad leaf surfaces of an uneven canopy of trees, hence, the forested slopes of sea-facing mountains in tropic tradewind areas. Even small garden tree patches "rain" softly on clear nights when a sea-wind is blowing, and let down drips in a steady stream to swell dried-out leaves and to channel down leaf midribs to the fibrous trunks of palms and tree-ferns. Once plants are cleared, the effective precipitation falls, rivers cease to flow, and the land becomes truly dry.

SAVANNAH FORESTRY

Wherever overgrazing plus fire or cut-and-burn forestry has ruined native forests, in particular towards the wet-dry tropics, closed grassland species of fire-prone and tough grasslands develop, closing out the tree seedbed and preventing good management practices. Further burning or cultivation may result in a depauperate grassland of low stock carrying capacity over the dry period, and patches of bare and eroded soils, low in nutrient states and at times acidic (pH 4–4.5) may develop. Blady grass (*Imperata cylindrica*) and other tropical forage grasses are stubborn, tough, and almost inpenetrable barriers to gardeners and stock, although they provide good mulch.

Given rains of 60–150 cm, a set of rough pioneer legumes are available for the rehabilitation of exhausted sites (including mine spoils and road embankments). Providing enough seed can be obtained, direct seeding in scratch holes or chiselled strips will result in the fast establishment of some, or all, of the species listed below, to which can be added *Leucaena* and *Albizia* species. Tropical grasses, scythed or mown 5–8 times annually, make good mulch for trees and gardens.

When using legumes, leaf-drop and nodulation will re-establish soil fertility. The canopies of *Acacia auriculiformis* or *A. mangium* will shade out and kill the grasses, so that fire intensity is reduced or eventually eliminated. Using these pioneer legumes as nurse crop, firewood, pulp timber, mulch, and honey sources, high-value timber such as rosewood, mahogany, and ebony can be introduced in lines or clearings in the first crop, and the gradation made to either high-value forestry or to sensible strip cultivation on a sustainable basis.

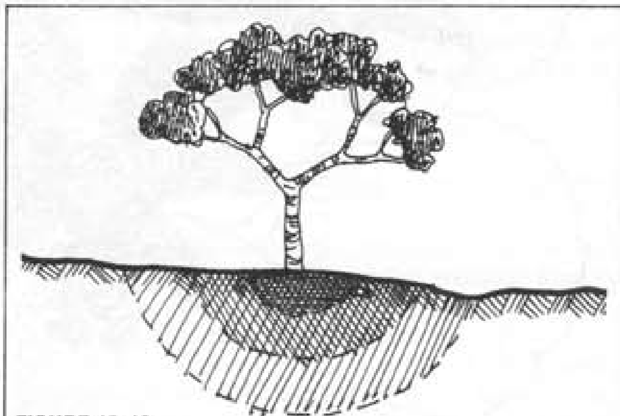


FIGURE 10.46

ZONES OF NITROGEN INTENSITY AROUND A TREE LEGUME.

Nitrogen will diffuse from the soil for up to 6 years after a tree is cut down, so the effects lasts long after the life of the tree. Intensity of nitrogen concentration falls in the outer root zones.

If *Leucaena, Samanea, Prosopis* and *Inga* are planted, a long-term forage system will evolve, providing replanting or rest periods are given for seedlings to re-establish. The only thing preventing or delaying savannah forestry is a lack of tree nurseries and seed sources of appropriate species, and this too presents an opportunity for a pioneering enterprise in the humid tropics. A very good selection of potential species can be found in the National Academy of Sciences publication referenced at the end of this chapter.

Species such as *Pterocarpus indicus* or *P. erinaceus* can be first seed-planted in a nursery stand, then coppiced for 2 m quickset planting in bore-holes in the field. Some species can be set out at 10 cm diameter, and make good timber trees.

PIONEER AND GRASS-EXCLUDING SPECIES, FIREWOODS

Acacia auriculiformis is an important pioneer for exhausted savannah and tropical soils, where over a very wide range of soils and sites it can defeat blady grass (*Imperata cylindrica*), restore fertility, provide firewood, and act as a tree nurse crop. It reduces fire, and provides good paper pulp. It coppices and self-seeds and is widely used in tropics as a shade and street tree. *A. mangium* has similar characteristics but is straight-stemmed and therefore better suited to forestry operations.

Sesbania grandiflora is a fast tropical pioneer, can be coppiced, and is a good forage tree, an excellent green manure in rice, and re-invigorates worn-out land. Exceptional nodulation. Grows to 10 m and provides good firewood. Wide soil tolerance, extensively used for eroded hill sites. Young leaves, pods, and flowers used for human food (36% crude protein). Seeds are 40% protein. Used as light shade crop, vine support. Good in crop. Frost and wind tender, life about 20 years. All food from this tree should be cooked. Exceptionally fast growing.

Calliandra collothyrsus. A stick wood coppicing species which defeats grasses and provides abundant firewood. Repairs exhausted soils and restores fertility.

Dalbergia sissoo is salt and frost tolerant, fast growing, and defeats grasses. It tolerates a wide range of soil types and can be quickset from large cuttings (India).

Enterolobium cyclocarpum is a durable timber tree with large pods, defeats grasses (Central America).

Mimosa scabrella of Brazil is a subtropical pioneer, provides good humus and a living fence.

Samanea saman (rain tree) is a very fast-growing large tree of the tropics and subtropics, with sugary pods. Grass grows well below. Wood is valuable, durable.

10.12
ANIMAL TRACTOR SYSTEMS

Following are two examples of animal tractor systems, either of which can be used to prepare soils and remove grasses or persistent weeds for evolution to garden and tree crop.

CHICKEN TRACTOR

Confined chicken flocks will remove all green ground cover and surface bulbils, depending on how many are confined on how big an area, thus killing out or consuming such plants as *Oxalis*, nut-grass, kikuyu, onion weed, and pasture species of *Convolvulus*.

Dano Gorsich, on a 0.5 ha farm on Moloka'i, Hawaii, has planned and executed a successful chicken tractor/garden system on a stony hillside site. The process is to fence 5–6 plots, and rotate a 40-chicken flock on these plots over a period of 18 months. As each fenced area is scratched bare, it is limed, raked, and sowed immediately to vegetable crop (typically *Brassica*, beans, peas, amaranth, cucurbits, radish, root crop).

The chickens are moved to Plot 2, and in about 6–8 weeks vegetables are in full production on Plot 1. As Dano also needs a cash crop, he has interplanted young papaya in Plot 1 amongst the vegetables. These grow strongly and succeed the vegetable layer, giving high shade, and (from the waste fruit), chicken forage in later rotations.

Thus the tractor system proceeds, with chickens

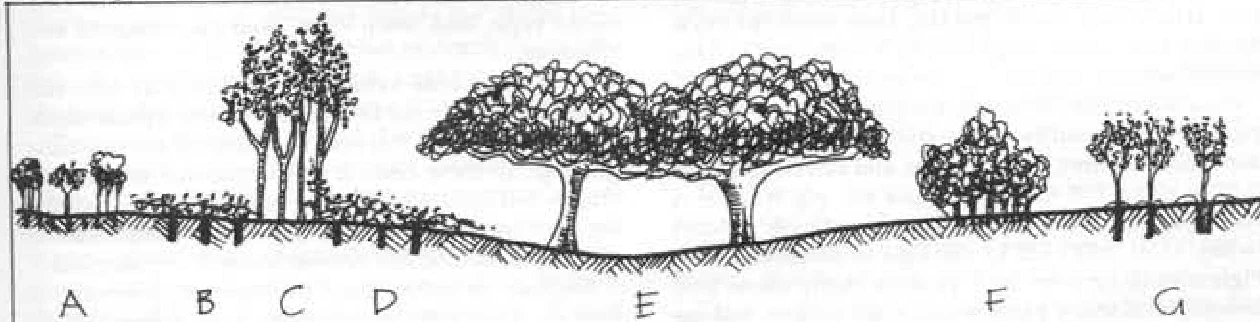


FIGURE 10.47
SAVANNAH FORESTRY.
A. High-value advanced seedlings planted in riplines. **B–D**. Chiselled area sown to Desmodium or lab-lab ground cover. **C**. Acacia strips sown in chiselled ground. **E**. Selected large figs, *Albizia, Inga*, set out in good soils around hollows. **F**. *Leucaena* and beancrop drilled in chiselled area. **G**. Quickset coppice forests of *Bauhinia, Pterocarpus*, some in deep holes.

pioneering the weeds, and vegetables and papaya succeeding them. In about 18 months to 2 years, a more perennial system succeeds the weed layer. Eggs, chickens, vegetables, and papaya are at modest commercial level, and both milk goats and chickens are let out onto the paths to eat greens when the pens are bare.

I have now seen numerous chicken tractors, all different, some with passionfruit fence/trellis crop, some just as vegetable gardens, and some for small fruit or herbaceous orchard. All are remarkable for lack of weeds and high production. In the more mature cycles, buckwheat, comfrey, millet, sunflower, and sorghum can be sown in the pens a few weeks before the chickens are returned, providing greens and grains.

Even rocky or rough country is so prepared for crop by chickens, the main cost being secure pen fencing. Strong fences also support vine crop, and a few larger legume trees provide high shade (*Tipuana tipu*, larger *Albizia*) for pens and crops.

Where chickens are to be the main crop, chicken forage plants replace vegetables and some fruit crop, and the system then provides all food. Near the house, a few small top-netted and secure rearing pens allow broody hens to replace the chickens culled. Normal weeds such as *Oxalis*, cleavers, dandelion, onion weed, nettle, and nut grass are excellent chicken fodders, as are any of the *Solanum* family (huckleberry, black nightshade, pepino, kangaroo apple, tomato, huskberry, Sodom apple, etc.)

PIG TRACTOR

The pig tractor follows the same technique but is more suited to 1–40 ha properties. Larger shrub–weeds (*Lantana*, gorse, blackberry) or deep–rooted weeds (*Convolvulus*, rhizomatous grasses, comfrey) call for a pig tractor. The density of pigs per pen should be at the proportion of 50/ha for full clearance of weeds. In practice, 0.5–2 ha plots are fenced, most economically using permanent electric fencing, which is much cheaper than chicken mesh fencing. Once each pen is bare (6–10 weeks) and rough–plowed by rooting pigs, it is easy to plant lucerne, comfrey sets, sunroot (Jerusalem artichoke), sweet potato, *Inga* trees, papaya, banana, and similar crops for pig forages, and to keep up this rotation until the pigs return to the pen.

On a large scale (20–40 ha), the pig tractor system can pioneer high–quality milk–cow pasture of chicory, dandelion, comfrey, dock, grasses, and clover, and cows follow along 2–3 months behind the pig tractor. A continous rotation is set up, and excess milk product (whey, skim milk) fed to the pigs as accessory food. Piglets ranging over such pasture rarely show iron anaemia deficiency, parasite cycles are broken, and the soil constantly improves in humus. Such large animals as pigs and cows need fenced tree strips, tree guards, and border hedgerow to supply tree forage crop.

Obviously, these intensive animal tractor systems can be a phase followed by tree crop, an accessory to tree crop, or a permanent feature of the mixed farm, or used seasonally to remove crop wastes and fallen fruits. Chickens, I feel, should be a permanent forage system in all mixed orchards.

10.13
GRASSLANDS AND RANGE MANAGEMENT

In view of the prevalence of livestock enterprises in the tropics, some guides to management are required for milk and beef or sheep production. The following management strategies can be implemented:

• THE ADDITON OF FORAGE SPECIES to grasslands. These can be grass legumes or trees; the latter providing foliage, food sugars, seed carbohydrates, or fruits.

• ENVIRONMENTAL CHANGES, particularly in terms of water storage and soil structure, irrigation, windbreak and shelter. Key fertiliser or trace elements can be added, and plant species can be maintained by slashing or light cultivation of pasture.

• CONSERVATION OF FORAGE by rotational or periodic rests from grazing, by using hays and silages, by supplying protein or urea supplements and molasses in drought, and by keeping stocking rates below the worst case conditions.

• STOCK MANAGEMENT, especially by well–planned buying and selling to keep numbers in tune with seasons and longer–term fluctuations, for example timing calving or buying in animals in spring or early summer, and selling them or dry cows in autumn to lessen winter feed demand. At the extreme, stock can be penned and fed harvested fodders. A sequence of species or a species polyculture can be planted to take best advantages of forages.

A mixture of legumes with a selected grass species plus some storable forage is ideal for the tropics. Most grazing systems can extend under palms, between large tree crops, or as a complex with belts of forage tree legumes yielding fodder, fruit, pods, or large seed for food concentrates. Each soil type, location, rainfall area, slope type, and main crop needs assessment and planning.

The leaf swards valued by graziers may also suit green–crop cover for orchardists where regular slashing for easy fruit harvest is practiced (or sporadic grazing). In these cases it is essential that the orchard crop is well established using manures before twining legumes are planted. Soils under slashed pastures are of excellent structure, and erosion is effectively stopped.

Elephant or banna grass (*Pennisetum purpureum*) is best on deep alluvial or coarse flats above 110 cm (alluvium) or 90 cm (coastal) rainfall. It reaches 2.5–4.5 m high, but can be grazed to 1 m or cut to 15 cm for forage and mulch. It needs a vigorous legume, e.g. *Leucaena* interplant, or forage legumes such as *Calopogon*, *Centrosema*, *Glycine* (in high rainfall tropics).

If a cool season is expected, autumn cutting should be later so that cool season regrowth is obtained. Banna grass can be set out as windbreak by burying hard slim pieces of 4–5 nodes horizontally at 8–10 cm depth in summer. Furrows should be manured and kept free of weeds until the stems shoot strongly. Permanent plots can be established, well-suited to feeding selected stall-fed dairy cattle. Accessory plots of bean trees, coconut, banana, etc. for diet variation, and palms for bedding, are ideal. Banna grass can carry 7 milk cows/ha if cut and hand-fed with *Leucaena* and sugar pods.

TROPICAL PASTURE GRASS SPECIES

Guinea grass: (*Panicum maximum*) This is a bunch grass for warm areas of more than 90–300 cm rain. It is drought resistant but yields best in humid areas. Frost-sensitive. Shade tolerant, and suits thin-crowned tree crop (often yields well under trees). Valuable in that growth is maintained in cloudy summer-autumn regimes. Grazed down to 15–20 cm. Combines well with twining legumes which climb on stiff stems. Suits rotational grazing (12–18 fields), interspersed sugar-pod trees and tree fruit forages. Drilled to 6 mm to establish. A first choice for sub-tropic and tropic pastures.

Kikuyu grass (*Pennisetum clandestinum*). Cold tolerant and grown from cool to tropical areas. Valuable for cooler uplands, thinner soils, and for good autumn growth if nitrogen-fixing trees (*Acacia, Leucaena, Prosopis, Albizia*) are established. Prefers light soils, red loams, and can be sown as runners or seed. Excellent for water spillways and erosion control. Few legumes tolerate the tight sward, so that trees for nitrogen are essential. *Desmodium, Glycine*, and white clover sod-drilled in autumn-cut areas can be tried.

Makarikari grass (*Panicum coloratum*). Bunch and spreading types for 40–90 cm rainfall. Tolerates alluvial fans, flood plains, black clay soils, red earths, and even semi-caked salted soils. Needs a year after seeding to establish, so suits rotational systems. Lucerne interplant can succeed in irrigated areas. Drilled at 1.3 cm, 2–3 kg/ha or planted from rooted cuttings. Valuable for winter-green feed, drought resistance. Suits long rotation grazing in open savannah of *Acacia*, sugar-pod trees. On black clay soils, purple pigeon grass (*Setaria porphyrantha*) may germinate better than makarikari.

Para grass (*Brachiaria mutica*). For warm areas of low frost intensity, valuable for swampy soils and at soaks, dams, waterholes. Provides good soil structure due to fibrous shallow roots. Can be grown with the forage legume phasey bean, greenleaf *Desmodium, Centrosoma*, puero. Ideal as a fenced-out reserve food for drought, to finish off animals for sale in poor seasons. Planted from cuttings at 2 x 2 m or seeded if seed is available. Do not plant where clogging of channels can be a problem or where other crops are to be grown. Can reach 4 m in one summer!

Sorghums (*Sorghum almum*), silk sorghum, and Sudan grass (*S. halapense*) are annual, biennial, or persistent from seed, and are of most use as broadcast-sown pioneers in slashed mulch at 50–90 cm rainfall. They can be used as pioneers with the perennials, as mulch in orchard strips, as emergency dry-season fodder, and as a garden mulch source. Easily grazed out, the sorghums provide birdseed, forage, and help control weeds. They are of particular use in early establishment and can be surface-sown.

Establishing perennial grass swards on weedy or eroded areas is a one to three year process. The best way to proceed is:

- Choose a land-forming system such as swaling, interception banks, or pitting. Try to establish some dams for irrigation above good soil types.
- Sow a pioneer grass such as molasses grass, *Sorghum almum*, or silk sorghum mixed with sawdust into slashed weeds, or drill selected grass and legumes after slashing.
- Burn molasses grass, or drill selected perennials and broadcast *Sorghum almum*.
- Concurrently with earth-forming, plant a mixture of leguminous trees along swales, through the area to be grassed at 30–100 metre strip spacing. Allow 2–3 years to grow with light grazing to year 3.
- Commence managed rotational grazing, and drill or broadcast forage legumes into established grasses. About 15–18 fields are necessary for rotation. On irrigated areas, some strip grazing is possible (use electric fences).

On rocky knolls, leguminous tree pioneers followed by kikuyu sward may succeed. Early furrows of banna grass provide erosion and wind control (at 30 m spacing) until tree legumes establish. At every stage, soil analysis and minimal mineral fertiliser amendments may be necessary, and with intensive grazing, sulphur and potash dressings are desirable.

TROPICAL FORAGES AND GREEN CROP

Desmanthus virgatus is a shrub to 3 m resembling *Leucaena* and tolerant of heavy cutting and browsing in the savannah tropics. It is vigorous and seeds are prolific, thus should be on range, not in field crop (7–70 t/ha/year).

Desmodium discolor is a browse shrub to 3 m, yields some 30 t/ha/year green fodder and is sown prior to rain as strips in rangeland. Also compatible with maize.

D. distortum. Perennial to 2 m. Good on acid soils (2–7 t/ha/year).

D. gyroides. Shrub to 4 m. Tolerates wet sites in tropics. Can be cut for forage (stems brittle).

D. nicaraguense. Excellent forage, wide soil range in tropics. Pioneer plant in grassland, for cut forage.

Tagasaste (*Chaemocytisus palmensis*). Tolerant and hardy to tropics, cool areas, widely used in New Zealand in dry areas for cut forage, pioneer, mulch, and nurse crop.

Honey Locust (*Gleditsia triacanthos*). Selected trees bear heavy loads of pods in dry subtropics; frost-hardy.

Thornless forms exist. Deep soil moisture is required in the dry season, but the tree is soil-tolerant and wind-hardy. Best trees are thornless, high sugar types.

Kiawe (*Prosopis pallida*). Staple pod forage on dry savannah sites in subtropics, dense wood, excellent firewood and termite resistant posts. 20% thornless trees on Hawaii. Non-invasive.

THE PASTURE LEGUMES OR FORAGE LEGUMES

Calapo (*Calopogonium mucunoides*). A short-lived twining perennial used mainly as a pioneer of burnt or slashed weed areas to smother weeds before permanent systems are established. It is suited only to low-frost coastal areas of high rainfall (above 125 cm) and is moderately shade tolerant. It reseeds, but shades out or can be grazed or cut out. High seedling vigour.

Centro (*Centrosema pubescens*). A twining perennial used in both pastures and grain crops. Prefers more than 125 cm rain, warm climate between the tropics. Excellent cut forage and soil-builder, tolerant of wide soil range, acid soils, short flooding, some frost. Ideal for guinea-grass permanent pastures, banna, pangola, and para grasses. Climbs to 14 m so is *not* suited to short perennial crops, bushes, small trees. Can be broadcast in burns or slash areas, or drilled. Seed may need hot water treatment, inoculation. Persists well under grazing.

Kenya white clover (*Trifolium semipilosum*). Persists well in shortgrass pastures, dairy strip grazing (more than 100 cm rainfall or irrigated). Flowers autumn and spring. Needs good seedbed, scarification, inoculation.

Haifa white clover (*Trifolium* spp.). Strain adapted to summer heat, subtropics, persists well, reseeds after drought. Good interplant together with woolly vetch.

Greenleaf desmodium (*Desmodium intortum*). Vigorous trailing perennial used as understory in tall orchards (after establishment). Affected by frost, needs more than 100 cm rain, but valuable for soil-building in sandy soils, for early spring and autumn growth. Tolerant of poor soils, and stands some waterlogging. Needs rotational grazing. Seeds need inoculant. Companion legume is *Glycine* for wind control.

Silverleaf desmodium (*D. uncinatum*). Trailing vigorous perennial for mulch in established orchards, rocky sites, pastures, wet (not boggy) areas and acid soils. Pods sticky, and some people get skin rashes if it is used in gardens.

Macro (*Macrotyloma axillare*—was *Dolichos axillaris*). Twining perennial, forming a dense sward. Needs more than 100 cm rain in light frost areas. Valuable in shallow ridge soils, tolerates some dry periods. Establishes readily.

Lab-lab (*Lablab purpureus*—was *Dolichos lablab*) Vigorous annual or short-lived perennial useful for soil-building and weed control. Grown as a forage and mulch legume wherever cowpeas succeed. Will stand sporadic grazing; kept in rotation or strip grazing. Good silage, compost, mulch, pioneer crop. Tolerates acid soil, rough seed-bed. Broadcast at 20 kg/ha, drill at 6–10 kg. Inoculation assists establishment. A good screen plant on trellis for watered dryland gardens. Pods and beans edible.

Glycine (*Neonotonia wightii*—was *Gylcine wightii*, *G. javanica*). Slender, twining perennial with deep roots. Cycles phosphates from deep soil layers. Resists drought well, but affected by frosts. Useful in cool subtropics and tropics. Good winter growth in pastures; main growth in summer. Often fenced out in late summer or early autumn as a winter reserve. Rainfall ideal at 80–180 cm. Does best on well-drained deep red soils, but also yellow clays, black cracking soils, areas not subject to waterlogging. Needs rotational grazing, rested in late spring. Good silage (with molasses), mulch, fertility restoration of soils. Good seedbed and inoculation desirable.

Lucerne (*Medicago sativa*). Grown from cool temperate to tropics, usually as a pure sward cut to baled hay, but also in well-managed pasture under rotation (allowing a year or so of light grazing). Grows from 55 cm and up rainfall, as it is deep rooted. Combines well with makarikari, sorghum. Regular resting is essential to persistence, and in pasture needs re-seeding every 4–8 years. Cut for hay just before flowering. Reseeded in cut sward by chisel seeding. Inoculation essential, and lime pelleting also essential in acid soils. 6–14 kg/ha sown, lighter on rain-fed areas, heavier if irrigated. Silage with molasses now popular, hay expensive and in high demand. Garden plots used for mulch, rabbit feed, seeds for sprouting.

Phasey bean (*Macroptilium lathyroides*—was *Phaseolus lathyroides*). Self-regenerating annual, long erect twining stems. Needs more than 75 cm rain, heavy soils. Can be sown with para grass in swampy areas, also with glycine.

Siratro (*Macroptilium atropurpureum*) Perennial legume, creeps, good root system. Warm areas of 75 cm or more rain, ideally 90–110 cm. Poor soil tolerant. Excellent contribution of nitrogen to grasses, e.g. Rhodes grass. Ideal for rotational grazing, readily established, resistant to nematodes. The basis of many excellent pastures.

Puero (*Pueraria phaseoloides*). Pioneer green and cover crop, perennial climber. Very vigorous as a smothering summer mat. Used in wet tropics. Palatable, good seedling vigor (can be broadcast). Can be kept in pastures if rotational grazing practiced, but also suits green manuring, orchards, garden mulch crop.

Stylo (*Stylosanthes guianensis*). Perennial pasture legume of warm areas, 90–400 cm rain. Good pioneer of poor acid soils, poor drainage, sands, rocky soils, hillsides. Combined with low grasses (signal grass, pangola). Sensitive to copper and phosphate deficiencies. Excellent mulch in tree systems in such soils, can be cut to silage. Surface-planted, wide range of inoculants. Many varieties. Suited to specific sites and climates. Some shrubby types are an excellent cassava interplant, or also suit banana/papaya once plants of fruits are established, as a slash mulch; often kept as a feed for dry season, suits fenced-off reserves (*seca* variety) Shades out in dense plantation but may be ideal establishment mulch.

Cowpea *(Vigna sinensis)*. A preferred annual cover crop and soil improver. Also with sorghum, maize, millet as a hay or mulch in established orchards.

Lupin (West Australian varieties of seed lupins). Excellent cover crop and seed in acid sandy or good soils. Inoculated, can be broadcast or sod seeded. Good winter green crop (annual) in vines, bush fruit crop.

Mung beans *(Vigna radiata—was Phaseolus aurlus)* Vigorous garden green crop, forage annual, hay or grain crop. Suits gardens and low crop systems. Annual.

Note: Serious attempts to establish green crop and productive perennial pasture should be prefaced by research into species. An excellent place to start is: Humphreys, L.R. *A Guide to Better Pastures for the Tropics and Subtropics,* Wright Stephenson & Co. Pub. Australia P/L, P.O. Box 113, Ermington, NSW 2115.

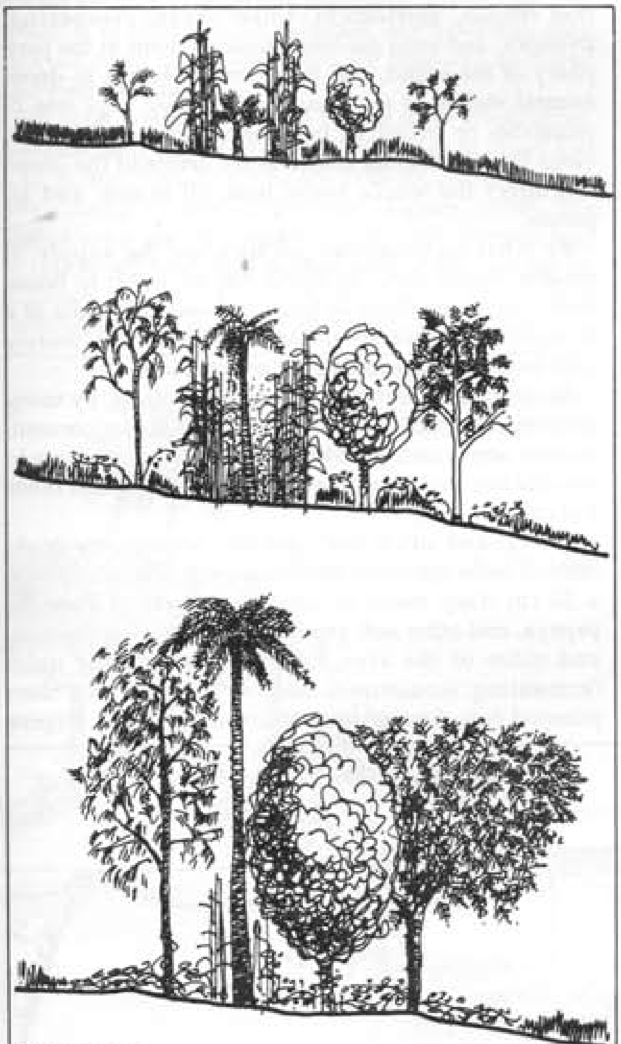


FIGURE 10.48
ROWS OF TROPICAL HEDGEROW AND WINDBREAK.
Evolution from *Pennisetum* hedge to a permanent palm-casuarina-legume windbreak over 2-5 years. Quickset *Erythrina* assists in early establishment as truncheons set in soil.

10.14
HUMID TROPICAL COAST STABILISATION AND SHELTERBELT

If we presume a fairly delicate sandy coastline, then we need to build a complex stable assembly from the wave break to 10–20 m inland. The natural profile of undisturbed beach vegetation is that of a convex profile into the wind, and these uncut shores are very stable.

TROPICAL HEDGEROW AND WINDBREAK

Deliberately-mixed hedgerow is a preoccupation, skill, and literature of the temperate zones (as these were the first to suffer enclosures of common lands), but the rape of the tropics has now proceeded so far and fast that pioneer hedgerow is a priority theme for tropical coasts and hill country. Due to ideal growing conditions in the climate, if not the soil, hedgerows quickly establish. A classical hedgerow for the tropics is given below.

Well-tried procedures are as follows: cultivate, manure, and place dripline along a hedgerow site, and set out (concurrently) a row of:

- Tall grasses or clump bamboo; *Pennisetum* is usual.
- Quickset cuttings of *Erythrina fusca* or *Jatrophe*.
- Seedlings of *Leucaena* or *Acacia*.
- Occasional palms as seedlings, preferably those with spiny trunks or mid-ribs.

The results can be as in **Figure 10.48**.

This is for field conditions. When first setting small orchard crop such as citrus or avocado (both wind tender), first cast up an earth ridge system and plant *Pennisetum* hedges every 30 m (100 feet) crosswind and (if possible) cross-slope. This may result in a series of parallel lines (if wind and slope coincide), or a diamond pattern (wind at an angle to slope), or a series of squares (wind and slope at right angles). Pay particular attention to the top of ridges in wind-prone areas.

As the young orchard grows, the *Pennisetum* at 30 m shelters it. Every second row of *Pennisetum* can be combined with *Leucaena,* and every third and every ridge row with *Acacia* and palms. The evolutions follow. Later, the inner rows can be removed as mulch.

Complicating the Hedgerow

Tomato trellis can be placed on *Leucaena*, and passionfruit on most trees. Mango itself is a good windbreak, *Eugenia* can replace some *Leucaena,* and we are on the way to a mixed hedgerow for wildlife, domestic forage, and food in the tropics. I would never neglect a clump bamboo as a source of structural field material and effective windbreak.

The cross-slope ridges early established become long-term soil and water traps, and accumulate mulch for later evolutions. These are a feature of the Tropical Crops Materials Centre on Moloka'i, and there one can see their uses and long-term evolution (under cultivation) into terraces of undoubted stabilty, as in **Figure 10.8**. Roads should be provided with concrete or stone fill at "X", the *downhill* side of the mounds. Permanent roads can be made after the terraces are formed.

10.15
LOW ISLAND AND CORAL CAY STRATEGIES

All coral sand cays and many low atolls lie within 28° of the equator, as do coral reef areas and sandy alkaline coasts. As many peoples live on atolls, very careful design approaches are needed to avoid the known risks of:

- Hurricane erosion and damage to plantations and coasts;
- Water table (water lens) pollution; and
- Poor nutrition due to a limited diet (usually high in carbohydrate and oxalic acids).

Additional design input is needed:

- To extend vegetable and fruit crop;
- To extend water storage and to conserve water;
- In conserving natural vegetation and unique birds, reptiles, and lagoon or reef fauna;
- To use shallow marine waters for aquaculture and pond fish; and
- In developing energy resources locally.

On atolls, we can expect soil pH values of from 8.0–9.5, sand abrasion, and basic mineral deficiency (especially iron, zinc, molybdenum, boron) in soils and plants. Elemental sulphur, iron sulphates, and humus added to garden soils and planting holes lower the pH. Humus sources are palm fronds, coconut husks, tree trunks, and leaf litter from such pioneer species as *Casuarina equisetifolia*, sea grape (*Coccolobus unifera*), coastal shrubs (*Scaevola, Tornefortia, Pemphis*), mangroves, and *Barringtonia* trees. All yield abundant litter for garden and tree holes.

We also can expect a thin coralline sand over a hardpan of caliche or calcrete. Calcrete is worsened by the application of superphosphate. Usually the guano from seabirds provides sufficient phosphates if colonies of terns, gulls, boobies, frigate birds, and shearwaters are protected or encouraged. Failing this, domestic pigeon, quail, pheasant, geese, ducks, and chickens can be kept as such predators as feral cats and foxes are usually absent.

PREVENTING WATER LENS POLLUTION

The sole natural sources of water on low islands are those biological storages such as we find in baobabs and coconuts (about 12 coconut trees provide for a person's drinking water for the year), and that water trapped in the sand below the caliche, floating on the seawater—the water lens of **Figure 10.49**.

As rain falls on the islands, it quickly absorbs in surface soils and leaks through the caliche to the water lens, which itself leaks slowly to sea between or below tide levels. As the beach berm is 2–4 m above sea level, and the inner atoll about 2–3 m, the delicacy of the situation in the event of water pollution is obvious. For this reason, settlement, toilet areas, processing, livestock, and even gardens should be kept to the periphery of the island, and the interior devoted to dense natural stands of food and native trees, kept free of pesticides or industrial pollutants and fuels. It is obvious that a polluting source at the centre of the island can affect the whole water lens, all plants, and all people.

By what methods can we increase the supply of potable water? First, by using run-off water to house tanks, the latter above or below ground and made of a reinforced cement–coral–sand mix, which is widely used in construction on all but remote atolls.

Secondly, and of most importance to plants, by using deep mulches, and by growing ever-abundant coconut, banana, arrowroot, papaya, legumes, and like plants to provide leaf and trunk materials for gardens and other tree crop.

Lastly, and often successfully, we can try leaf-ferment seals (gleys) of gently-sloped coral pits, where a 20 cm deep mash or shredded mass of banana, papaya, and other soft green leaf is applied to the base and sides of the area, covered with plastic until fermenting (sometimes only 4–5 days), and then pumped full of water from the freshwater lens (**Figure**

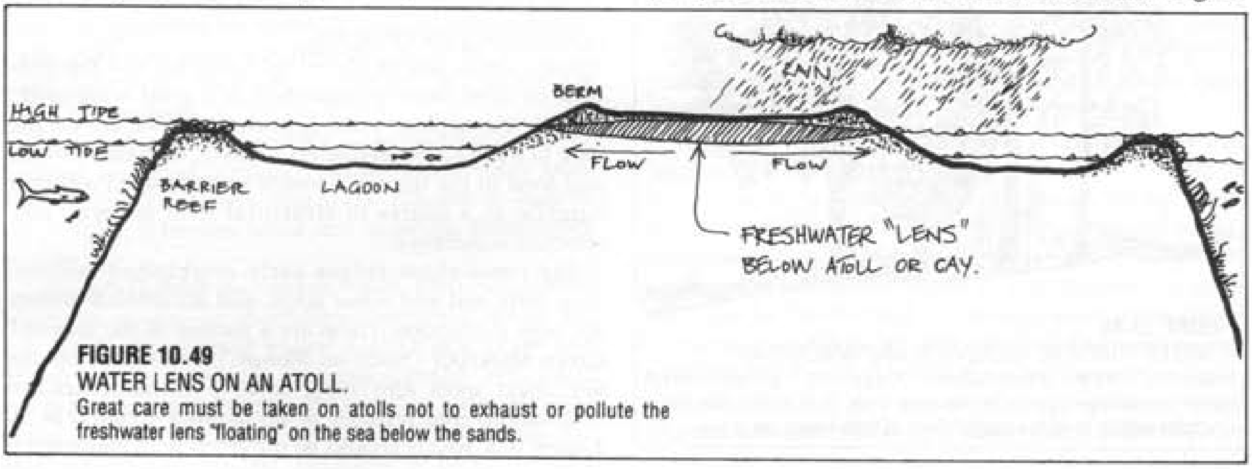


FIGURE 10.49
WATER LENS ON AN ATOLL.
Great care must be taken on atolls not to exhaust or pollute the freshwater lens "floating" on the sea below the sands.

7.19).

Made carefully, such surface ponds will also take roof run-off. Success follows careful trials at small scale to get the system working, then scaling up to significant ponds for ducks and garden water, water leaf crop, and animal drinking water. As such ponds are often a source of cross-infection in children, it is sensible to swim in the lagoon, and to drink tank water. Seawater serves also for many toilet uses.

PLANTING TREES ON CORAL CAYS

To plant trees, we need to clear off a patch of topsoil and break open the caliche, making a pit about 40 x 40 cms and 60–80 cm deep. In this pit we make a humus pile of domestic and plant wastes, plus some sulphur and the mineral trace elements, and plant a coconut or other seedling tree.

The tree roots spread out above the caliche layer, and feeder roots go below the caliche to the water lens, which is usually 0.75–1.0 m down, and 1.0–2.0 m deep as a saturated sand layer. Trees are thus well anchored and easily obtain water.

To plant gardens, we have two or three possibilities. The first (and best) is to open a pit garden of about 8 m x 15 m, and sloped for stability to about 2 m deep, thus often damp or wet on the base (**Figure 10.50**). The sloped sides are stabilised, as steps, with coconut logs or caliche, and the spoil banked around the rim. Mulch is thickly applied to the base and behind the stepped terraces, and when this is rotted, a range of plants are grown. From base to crown, some such sequence as follows is appropriate:

1. BASE (damp, mulch) watercress, parsley, chives, *Brassica*, taro, kangkong, salad greens generally.
2. FIRST TERRACE (18–25 cm above base) tomatoes, peppers, taro, sweet corn, beans, peas, taller crop.
3. SECOND TERRACE(25–60 cm above base). Banana and papaya, sweet potato, cassava (all provide mulch).
4. THIRD, OR HIGHEST, TERRACE. Cassava, sweet potato, banana, dry-tolerant vegetable crop, and mulch trees such as *Leucaena*, *Glyricidia*, *Tipuana tipu*, *Moringa oleifera*, and local tree and shrub legumes to provide leaf mulch and partial shade; palms for frond mulch and high shade, vines to climb on these (passionfruit, four-winged bean).

Secondly, under some light palm-legume canopies, boxes of palm logs will hold thick mulch and household waste for surface gardens. These can be planted as beds of potato, yam, sweet potato, and normal vegetable crop. The thicker the mulch, the less watering needed.

Thus, log boxes, pits, thick mulch, and high shade canopy are the essentials for good atoll gardens. Staples are coconut, root crop, fruits, and normal salad vegetables plus fish and shellfish from the lagoons or coasts.

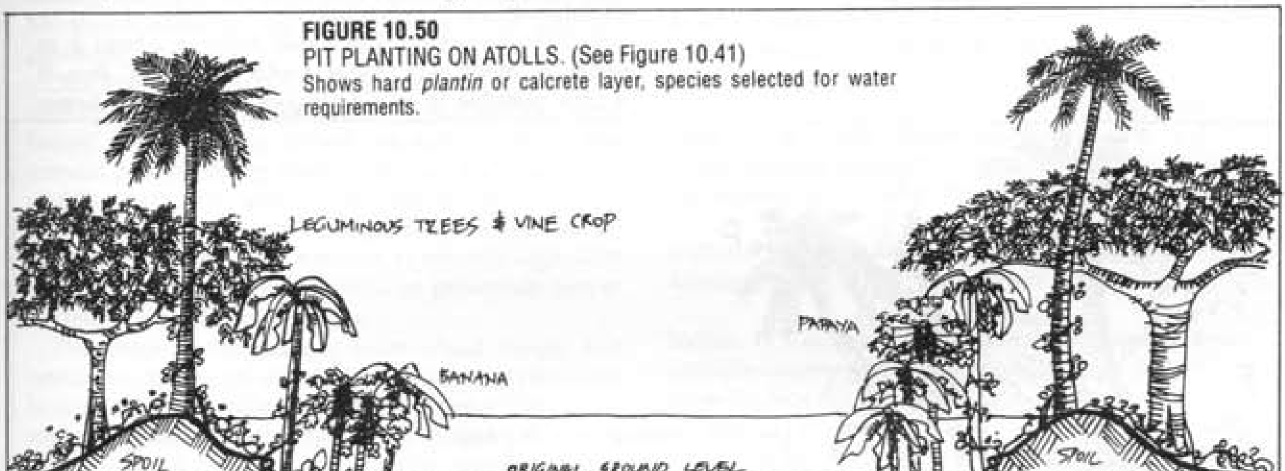


FIGURE 10.50
PIT PLANTING ON ATOLLS. (See Figure 10.41)
Shows hard *plantin* or calcrete layer, species selected for water requirements.

AVOIDING AND REDUCING HURRICANE DAMAGE

Access to atolls is traditionally by boats in reef gaps and today by light planes. When blowing a gap for a reef entry, or clearing a landing strip for a plane, great care must be taken not to open a wave or wind gap to gales, or any atoll can literally wash away. Thus, reef entries are cut on the slant through the reef at the east or west quarters (winds blow southeast to northwest south of the equator, northeast to southwest north or the equator). In fact, reef gaps should be in the most sheltered sector of the reef in any winds, and also just wide enough (6–10 m) to admit a vessel or barge.

Airstrips are also aligned about 20° off prevailing winds, and both ends and sides should be of tall palms and trees, especially those borders on the coast, so that light planes drop in, using their rudders to straighten up below tree crown level. Airstrips carelessly made have destroyed whole islands when hurricane winds have cut them in two following the line of the air strip.

For the same reasons, the sandy coasts of all atolls and cays need a sequence of perennial shelterbelt to hold the shoreline against hurricanes. This starts on the beach as convolvulus (*Ipomoea pescaprae*) and beach pea, rise on the beach berm to a dense shrubbery of vines, *Tournefortia*, *Scaevola*, and in sheltered bays mangroves, and is backed by a 5–6 tree deep layer of coconut palm, *Casuarina*, *Coccifera*, *Barringtonia* and other hardy beach trees (**Figure 10.51**). It is behind this dense frontline windbreak that we site houses, gardens, and productive trees, which will produce in shelter but not as exposed systems.

EXTENDING DIET

People who live on small islands, and indeed small traditional villages generally, may exist eating a very few starchy root foods plus banana, with fish for protein. It is quite probable that mineral deficiencies and low vitamin/high carbohydrate diets can impair health. Thus, a well–mulched pit garden, and a well–selected introduction of tree fruits (guava, citrus generally, vine fruits, and a polyculture of minor fruits and nuts) greatly extends and buffers the diet. The addition of (in particular) zinc and iron to mulched soils, and periodic tests of leaf content of such minerals serves to eliminate problems due to restricted diets and highly alkaline soils. Even on high islands, soils can be devoid of, or have, very limited mineral rocks, and soils may need trace elements.

Almost every island group has unique plant and animal species, some of great value directly, others of value in that they exist and demonstrate new forms and behaviours. Such groups as land crabs (derived from ghost crabs, shore crabs, and hermit crabs) do special work as mulch shredders, scavengers, larval insect eaters, and may form a valued food resource. Giant tortoises are also excellent scavengers of fallen fruits, and keep grasses below palms neatly–trimmed, while putting on a considerable annual growth. Marine iguanas, giant lizards (the Komodo dragon), flightless or specialised birds, and rare plant and animal survivors of older land masses are not only common but usual on islands. All need careful preservation and assessment for their special values, and many provide useful functions in polycultures.

At low tide (even the usual tides of about 1 m variation) atolls may almost double their "dry" area. It is thus possible to modify lagoon and reef for better

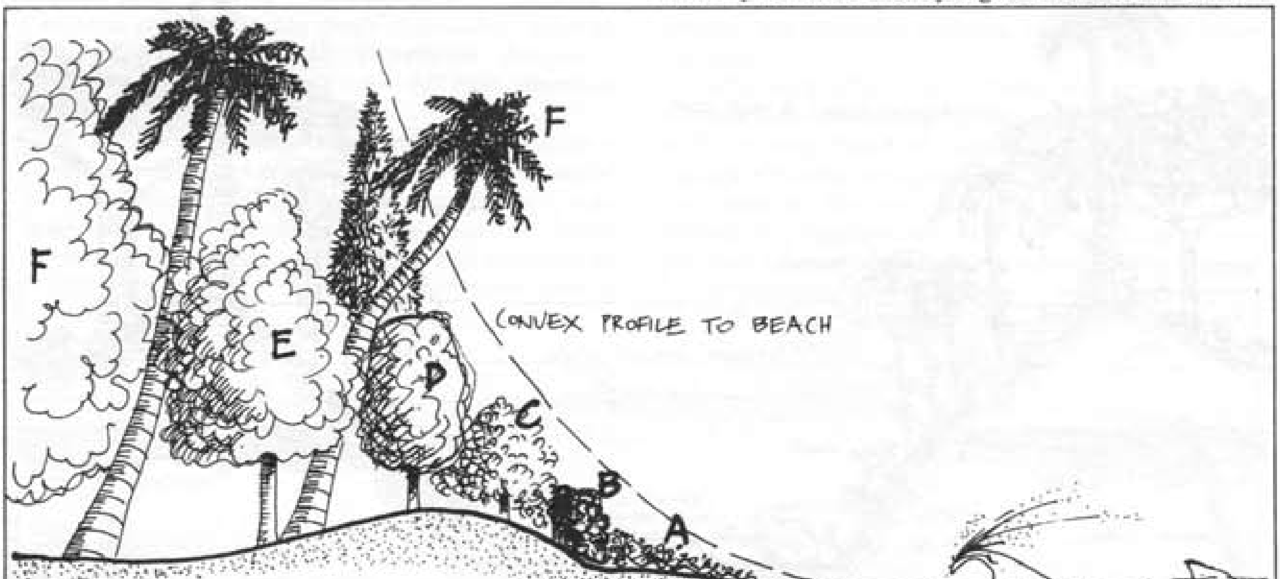


FIGURE 10.51
SEA COAST PLANTING
A. Beach convolvulus. **B**. *Scaevola*. **C**. *Tournefortia*. **D**. *Barringtonia*. **E**. Sea grape (*Coccoloba*). **F**. Date or coconut palm, Casuarina behind beach berm. This profile is stable.

conservation and feeding of economically useful fish, shellfish, and marine plants such as mangroves, or to consolidate and protect shorelines with coral-block breakwaters. There are many such marine impoundments throughout the Polynesian world, and new marine breeding techniques are bringing into cultivation such species as trochus, turtles, many inshore mullet, milkfish, and edible seaweeds.

Because of the frequent internal (atoll) or external (annular reef) lagoons in or around low islands, designers and residents have extensive quiet waters in which to trial a wide variety of productive maricultures, shelters for fish, breeding places, and undersea constructs generally. The daily flux of tides through reef outlets brings a regular fish movement well-known to indigenous peoples.

ISLAND ENERGY RESOURCES

Islands in oceanic energy flows behave very much like "bluff bodies" in streams. Tide, waves generated by winds, winds, and the water crashing over low reef areas and flowing out of constricted reef inlets present good opportunities for energy generation locally. Reliable biogas technologies now widely used in Asia, and the less reliable wind-electric systems, can also be used for energy generation.

Solid fuels from coconut husks, fast-grown coppicing legumes, fronds of palms, and *Casuarina* stands are always available on well-planned islands. Climates are usually mild, and the main fuel needs (for cooking) can be much reduced by a vegetable-fruit garden development.

One area all atolls and islands can develop is that of tide-flow turbines (these can be propellers, or "egg-beater" catenary-curve vertical axis turbines). Coral and cement provide strong anchors for such turbines at reef outlets. Both tidal and ocean current flow provides dense energy power at 1kW/square metre/second of flow, so that a few such turbines at selected high-flow sites can provide either electrical or pneumatic power for island workshops and lights.

The above outline should assist island design; but one factor that we cannot design for is that of rising sea levels. Many of today's atolls will simply be over-topped or washed away by a very modest rise in sea levels, which is expected to occur over the next decades. For these sites, early evacuation is the best action!

10.16 DESIGNERS' CHECKLIST

Maximise tree crop, herbaceous perennials (banana, papaya, arrowroot, taro) and plan a multi-tier system integrating windbreak, forest, orchard, understory, and ground cover.

Complete earth-shaping before setting out plant systems.

Choose adapted high-value foods for intensive (mulched) home gardens; allow 30-90 species in Zone 1, but concentrate on 7-20 high-value crops in Zone 2.

Avoid bare soil systems in all areas.

Design a careful plant/animal assembly related to culture, market, processing, available labour, and value to village.

Design houses and villages for low-energy climate control.

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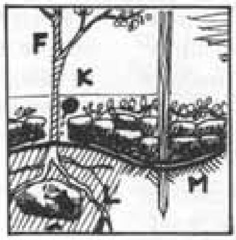


Chapter 11

DRYLAND STRATEGIES

The dunes, like harmonic chords, multiply and repeat the notes of the rustling, shifting sands... you now hear what sounds like the sonorous music of distant drums— roll after roll...

(Quilici, 1969, on the Tobol, or music of the dunes)

11.1 INTRODUCTION

The development of conservative strategies for the preservation of dryland species, and for the responsible human use and management of arid lands is probably the world's most pressing problem in landscape management. Only sporadic world attention is given to famine or drought in arid areas, with such "sudden" emergencies consuming great quantities of resources and finance, much of which is wasted in mismanagement.

Problems of aridity, salted soils, and long-term drought can *always* be expected where we venture into desert borders with pastoralism and cropping, for added to the natural background fluctuations of rainfall due to earth and moon orbits, and solar radiation variance, we as expoloiters add deforestation, soil erosion, and the consequent salting of waters and soils. All desert areas are extending; many dryland areas are being created, and antecedent plant and animal species are thereby brought to extinction.

A great many arid-area species are not so much dry-adapted as drought-evading. Plants dry off, cease growth, or exist only as seeds and tubers in drought. Many trees are dry-deciduous, evading the worst effects of drought in a leafless state, but truly drought-adapted plant species also exist, and use wax, insulation, reduced transpiration, and large water storage organs to withstand droughts. Animals aestivate, migrate to humid areas, or take refuge near oases and wetter areas. Many animals get sufficient water by eating succulent vegetation, by browsing at night to take advantage of condensation, or by predation on insects and other species of animals. Almost all small animals burrow by day to escape soil temperature fluctuations, often to 1 or 2 m deep. Some termite colonies develop deep galleries (to 40 m) to mine water, and also arrange air conditioning by adapted permeable surface nest structures.

Increasing desertification of agricultural lands has focused world attention on salt and drought-tolerant plant species of potential use. Gary Nabham (in *Annals of Earth* IV(1), 1986) has totalled 450 edible plant species for the Sonoran and Great Basin deserts of the North American interior (20% of the total species). The semi-arid or transitional areas are particularly species-rich, thus desertification is taking a rapid toll on potential useful plant diversity. Of the 936 woody plants in the West Australian wheat-belt, 45% are at risk. Large reserves are urgently needed; the present reserves in arid lands are "entirely inadequate to conserve even a usual proportion of the genetic variation..." (Nabham, *ibid.*)

Cold high mountain deserts like the Gobi have some 60 flowering plants, and 360 species of birds (*Geo* 7[4] 1986), while large areas of the arid Sahara have 6–8 plant species in total, and recent deserts such as the Thar some 15–18 species. Most of the world arid species lie in the Kalahari, Sonoran, and Australian deserts.

Arid lands are areas where direct evaporation exceeds rainfall, and where annual precipitation averages fall below 80 cm, and as low as 1 cm (sometimes only as dew). Although the greater part of these areas are hot desert, there are substantial montane hot-cold deserts, and very cold desert areas near the north and south polar regions. Typically, an extensive hot desert area consists of a savannah edge towards more humid monsoon areas, a Mediterranean climate edge, extensive scattered shrub–forb associations (**forbs** are any non–grass or herbaceous plants), dunes on harder pavement areas, and almost bare pavements of harder rocks with faceted pebbles (gibber plain or reg).

Where over–grazing has not been the dominant feature of land use, a desert may present an eye–level appearance of a low–crowned forest with shrub understorey, and some areas may be as rich or richer in plant species than a more humid forest environment. In detail, however, there will usually be larger or smaller areas of bare soil between all major plant clumps or species. Closer inspection may reveal a fungal–algal–lichen *(cryptogam)* crust on the bare areas, more or less intact depending on the frequency of hoofed animals. This cryptogamic crust is a critical and delicate feature preventing wind erosion; its preservation is essential for soil stability.

Some features of the deserts are:

- Plants produce copious seed with long viability; seed is often wind–dispersed.
- Termites and ants are more effective than worms as soil aerators and decomposers.
- Rain may fall in mosaic patterns, so that vegetation is also a varied mosaic of fire and rain, and ephemeral plants at different response stages from growth to decay are evident. New generations of shrubs may experience favourable seedling conditions as rarely as every 7–20 years. This then becomes the period of **recruitment** of new forests or shrublands.
- Much of the water run–off system may end not in rivers but in inland salt–pans or basins (*endorheic* drainage), from which all water eventually evaporates.
- Normal erosion is by wind, but rare cloudbursts shape the main erosion features and move vast quantities of loose material from the hills in turbulent stream flow. Wind transports materials locally in dust storms.
- Animals burrow, seek shade, or are nocturnal in order to conserve water; many are highly adapted for water conservation.
- Plant associations may be very varied in response to changes in long–term aspects such as slope, soil depth, salinity, browsing intensity, pH, and rock type.

SEMI–ARID areas have steppe, scrub, and low forest vegetation, ARID is steppe and scattered low shrubs, and true DESERT has little but oases and ephemeral vegetation appearing after the rare rains. Deserts have a rainfall classification of:

- Hyperarid: 0–2 cm annual average (e.g. Atacama, Namib desert, central Sahara).
- Extremely dry: 2–5 cm annual average.
- Arid: 5–15 cm annual average (e.g. Mohave, Sonora, Sahara margins).
- Semi–arid: 15–20 cm, maximum 40 cm (much of the Australian deserts, Asian deserts, Kalahari).

Above 40 cm, and to 75 or 100 cm rainfall we have (potentially) dry savannah forests; and it is up to this latter level that we will be dealing with in this chapter. Rainfall is not dependable in arid areas, with a normal 30% variation, and a potential 90% variation in any one year. Potential evaporation can range from values of 700 cm/year in hyperarid areas to 100 cm in steppe.

We can also regard the polar ice–caps as hyperarid (for precipitation) but evaporation levels are very low; wind removal of snow replaces evaporation. Both the very cold and hyperarid hot deserts have one thing in common—they mummify and preserve a great range of organic and fabricated substances, which presents a management problem when dealing with pollution, as breakdown of most organic substances can be very slow in the absence of water.

A paradox in almost all large desert or arid areas is the existence of two types of more humid environments: EXOTIC RIVERS which flow in from better–watered or forested regions, and OASES. There is a third, invisible water resource, that of AQUIFERS (underground waters). All must be used with great caution, as water in all of these resources can be locally exhausted, and aquifers can be depleted over vast areas by immodest use (as they have been in the USA). This misuse can cause widespread subsidence, collapse of the aquifer, and a permanent disappearance of those oases which were in depressions fed by the aquifer.

Instead of concentrating on exotic water in deserts, we should attempt to *increase the input* of water into the aquifers, soils, and streams; and to re–humidify the desert air by planting trees and protecting existing vegetation. It is the presence of trees and shrubs, transpiring rather than evaporating water, that keep the desert salts from evaporating at soil level. Once evaporation alone operates, capillary action quickly brings subsurface salts to the surface as magnesium, sodium, calcium, and potassium compounds (chlorides, sulphates, carbonates) and we can no longer establish vegetative cover.

When we talk of arid lands, we should also remember equatorial low islands, unstabilised sand dunes in midsummer even in cool climates, and whole periods of relative drought even in more humid areas (including the dry winters in many subtropical areas). That is why it is important to specify pioneering and drought–hardy plants for many situations, and why any strategy to get water into soil, and keep it there, is worthwhile. There are large areas of Mediterranean climate on desert borders which are "arid" if they have deep sands and poor water retention.

A profound question to ask about deserts concerns our basic usage. Livestock herding has been traditional—and devastating. Australians, Peruvians and Africans, Arabs, and Tibetans have all used arid areas for herding. Aboriginal Australians managed better, by harvesting the natural abundance of deserts so that the artifical stress of herds was not superimposed on the natural stresses of dry seasons.

We should re–think our strategies of desert use, and the way we occupy arid lands. It is possible to establish a carefully–developed core settlement, to set out hardy plants for many kilometres along favourable areas or CORRIDORS and to take advantage of the rare rains to establish a wide biological resource for dry years. It is not possible to count on permanent cropping or herding in regions that experience one good year in every 4–9 years. As for desert revegetation, by far the most effective and cheapest strategy is to exclude browsing animals from headwater areas, when after a few years thousands of young plants may establish.

Desert borders are now used for a seasonally and uncertain production of wheat, barley, millets, and sorghums. About one year in four produces a reasonable crop, but severe wind erosion and dust storms make this a precarious use of such delicate soils. Herding and extensive livestock systems also occupy great areas of the deserts, with seasonal or nomadic herding in north Africa and southwest Asia.

If we look at actual income *versus* land use, the Central Desert of Australia allots some 73% of the area to pastoralism, and only 27% to Aboriginal reserves and conservation areas. However, income is 15% from pastoralism, 76% from tourism, and 7–8% from mining in small areas. Even the mining is a "tourist industry" where it concentrates on precious stones, and Aboriginal art is a large part of the tourist interest. Pastoralism and mining are publicly subsidised, and has a grossly unwarranted system of direct and indirect supports, producing a largely surplus product for the world market. No wonder pastoralists must maintain a powerful lobby in the halls of government!

People rarely want to live in the desert—it is an expensive place to maintain a high standard of comfort in modern terms. But they love to visit, and to see wildlife, genuine tribal art, and the landscape itself. To Aboriginal people, the land is life itself; they are a part of the whole, and their art reflects this.

Deserts are inspirational for designers. Not only do the hills reveal patterns, rock types, and processes of erosion, but as the light changes from early dawn to late evening, new insights arise from the shadowed and light areas. What is often unclear on the ground becomes part of a whole pattern if seen from hills or the air. When we understand these many patterns, the distribution of materials and organisms makes sense, and we are able to creatively inhabit the landscape. It is little wonder that desert peoples, in the great silences, beauty, and vastness of nature, arrive at profound mystical pattern concepts. Only the confined oasis– or town–dweller concentrates on the ephemera of finance, commerce, and conduct. In the open, survival demands sensitive reaction to environmental imperatives.

11.2
PRECIPITATION

Rain occurs in deserts as a lesser part of the normal cyclonic, convectional, or orographic rains occurring elsewhere. Both warm, unstable tropical air masses and cold westerly rain may be entrained into air cell circulation over deserts, but there is a significant proportion of convectional rain due to local heating over sands, rocks, and bare soils. Only in some deserts does rain fall fairly reliably in a seasonal distribution, in areas affected by monsoon borders or westerly coastal belts. Elsewhere, rain is episodic and averages are meaningless in that many years may pass at any one place without rain. There are the natural deserts (the Namibian coastal areas and the Atacama) where offshore winds and cold sea currents ensure that rain is rare or virtually absent. Such areas are treeless, and depend on fogs and dew alone for plant growth.

As dew may be critical to plant survival, dew traps of stone, scattered shrubs, or even vertical metal screens to 1 m high are strategies to catch moisture. Moroccan foresters are contemplating such metal screens to condense dew and to thereby establish shrubs, which in turn will become moisture condensers.

OPPORTUNISTIC RESPONSES TO PRECIPITATION

A rainstorm 8–12 mm produces run–off sufficient to start headwater stream flow, and only the occasional downpour of torrential convectional rain, or the heavy rains of monsoons and tradewinds over headwater streams remote from the desert produce river flow down the braided or sandy water networks that thread through the desert.

For tribespeople and the mobile fauna of the desert, distant rain is the trigger that sets off a whole sequence of migration and perhaps a subsequent intensive breeding programme. Just as we can write a dissertation on the phrase *Om mani padme hum*, so we can write essays on such simple concept–words as "walkabout" for Central Australian tribes. Rather than being an arbitrary, willful, or unpredictable movement that the calendar–regulated Europeans see it to be, walkabout translates as something like:

> Our scouts saw thunderstorms to the far north; if we go now we can arrive in time to harvest some of the birds, animals, and plants that will respond to rain, and to follow the water to the waterholes that will fill with freshwater and give us fish, turtle, and frogs for a few months. We must go now, in time to celebrate the cycle of plenty that comes from the rain.

Thus we can see such movements as being sensible, planned, and appropriate to an environment which presents rare opportunities to harvest the varied resources provided by rain, to visit newly–regenerated country, and to lighten the burden of resource pressure on favoured home areas, so that they can regenerate as reserves for hard times.

The response of the desert to rain is truly remarkable. Ephemeral plants carpet the ground, and flowers and seed are produced in abundance. Buried tubers throw out great patches of melon, bean, and yam vines. Shrubs or trees may produce numerous seedlings in areas where few young trees existed. In the streams and

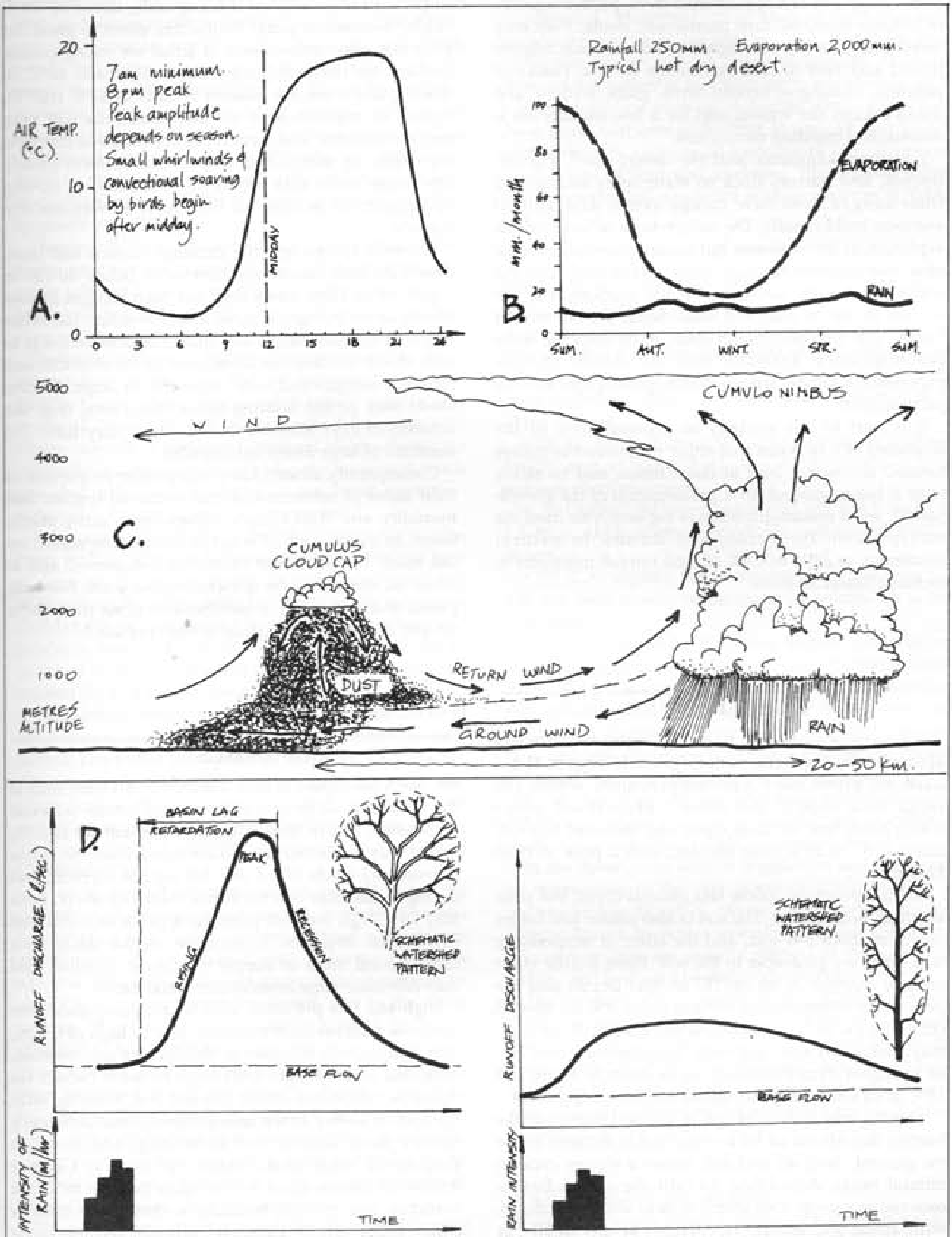


FIGURE 11.1

SOME CLIMATIC FACTORS IN DRYLANDS.

A. Daily temperature range typical of hot deserts. Soil temperatures may lag behind, and exceed, these extremes. Convectional air columns usually occur at about 1–3 pm, and die out at dusk.

B. Rainfall (here in South Australia) may never exceed potential evaporation, hence the importance of infiltrating runoff into soils.

C. Dust storms, raised by fierce downdraughts before convectional storms, are often followed by rain; pitting of soils (see FIGURE 11.15) prevents dust lift in winds.

D. Dryland flood sequences are moderated by retardation basins, and the form of the catchment; most runoff (35%) occurs in headwaters, much less in main streams (0–5%) unless in widespread rains.

pools, frogs and fish appear from mud-packed retreats, or invade from the rare permanent pools. Fish may breed and grow in a few months, and sea-birds migrate inland and nest to take advantage of this. Flocks of pelicans, flamingos, herons, terns, gulls, waders, and ducks occupy the waters, and for a few months life is riotous, and breeding unconfined.

Antelope, kangaroo, and the desert quail, pigeon, finches, and parrots flock to waterholes and spread their ranges over new forage areas, and animal numbers build rapidly. The longer-term collapse of this explosion of life is slower but usually inevitable. Some new tree generations may have established, but the waters turn salty, dry up, and life scatters, dies, or returns to rest in mud and sand. Seeds are blown and buried, and the desert waits again. Birds disperse, as do the migratory animals, and the desert fringes experience a sudden irruption of migrating species. The party is over.

It is part of our strategy to capture some of the estimated 88% of water that either evaporates or rushes unused across the land at these times, and to safely store it below ground for a prolongation of the growth period, and a rehumidification of the desert air itself via transpiration from trees and shrubs. In natural conditions, as little as 0.8% of total rainfall infiltrates to recharge desert aquifers.

11.3 TEMPERATURE

The air temperature (up to 60 m height) over deserts approximates the daily pattern given in **Figure 11.1**; I have not given the 6 a.m. temperatures, which can range from 8–30°C, but show a generalised graph which holds true for most cases, and indicates a rise of about 10°C to 25°C over the day, with a peak at from 12–3 p.m.

Soil temperatures follow this general curve, but peak about an hour earlier. The soil is also colder just before dawn, at about 5–6 a.m., and the effect of temperature falls off as we go deeper in the soil. There is little effect of *daily* changes at 30 cm (12 inches) depth, and the peak surface temperature reduces about 2°C for every 5 cm depth (or 15°C in 30 cm), so that soils at 30 cm deep may have fairly constant daily temperatures some 5°C or so higher than the lowest surface temperature, and 15°C or so lower than the highest surface temperature.

Another way to look at this is that soil evens out the heating that affects air for a considerable distance above the ground. Both air and soil follow a slower cycle of annual range depending on latitude and radiation received in season. This affects soils to about 2 m depth, with about 5°C annual fluctuation at this depth, or about the same fluctuation that we experience in underground houses and cellars.

Soils also can gain and hold much higher levels of heat than air, and at 5 cm depth, in favourable sun slopes and in poorly conducting soils, about 60–70°C can be reached at peak! While this effect is good for solar hot water collectors, it is lethal for young plants. Surface air temperatures frequently reach 30°C in deserts, and there are isolated records of 52°C (125°F). Layers of super-heated air just above the soil may become unstable, and form rapid convectional currents, especially on sun-facing slopes. Cumuliform clouds can arise from this effect as thermals or strong updraughts, or as clear-air turbulence in very hot dry periods.

In order to espcape the extreme surface soil heat, desert animals commonly burrow to below 30 cm in depth, or in some cases seek out high refuges in low shrubs or on stumps or posts in hot weather. The other way that animals escape soil and air heat extremes is to seek shade, become nocturnal, and to develop efficient cooling strategies and water economy. In larger species, shade may be the limiting factor in survival (e.g. the amount of cave shelters in the desert may limit the numbers of large desert marsupials).

Consequently, deserts have a far greater proportion of their fauna as subterranean and nocturnal species. Soil humidity also rises steeply, especially in dune sands. Given an average 4% of water in the top one metre, we can reach 10–20% water content at 2–6 metres, and at 20–60 m, there may be quite saturated soils. For both plants and animals, it is preferable to draw from these deeper, cooler, and more humid layers of soil.

11.4 SOILS

We normally expect to find dominantly alkaline soils in the waterways of deserts, with areas of surface salts and carbonates. It is in these alkaline areas that we usually locate our settlements, to take advantage of water run-off. pH levels of 8.5 and 9.0 are not atypical, and drying waterholes can reach pH values of 10–11. Soils may have high nutrient potential if pH is adjusted and if water for irrigation is available. Acidic sandy soils form around areas of deeply weathered granites, and may dominate large areas of these landscapes.

High and low pH areas have (as a consequence) low available mineral trace elements, and in high pH, zinc, iron, copper, and manganese deficiencies are common, indicated in crops and fruit trees by such factors (in citrus) as interveinal colour loss and leaf thinning, with tip curl in severe cases (manganese). Zinc deficiency causes more severe leaf yellowing, and is often associated with manganese deficiency. Copper deficiency causes giant leaves, gum pockets in citrus branches, and multiple budding or trunking in trees or citrus. Foliar sprays, elemental sulphur, and oxides or sulphates of the deficient elements can be used.

Special problems may be caused by non-wetting sands (a fungus is responsible), and high salt levels in water or soils. Bentonite or humus will ameliorate the "non–wetting" problem, as do swales and raised beds with high edges to prevent water run–off. Salt problems can sometimes be solved by flushing beds with fresh water, but if the water source is itself salty, salinity needs the combined solutions of humus production, perhaps a ponding period of water with algae production and water crop, ionic or distillation treatments, and a choice of salt–tolerant crop. Free-draining sands can be irrigated with salt levels in water much higher than will be tolerated as spray irrigation by plants (to 1500 ppm).

Despite all these problems, we can usually establish home gardens and adapted tree crop systems, and many selected areas (especially near scarps, rivers, hills, or ranges) will grow excellent fruit, vegetable, and tree crop with appropriate water run–off harvesting.

Perhaps the most important thing to remember about any activity in desert is that the natural systems are fragile. Good management and constant appraisal is essential. *Small* systems may be called for, especially where run–off is harvested. Natural yields should be carefully assessed, and broadscale or grand trials avoided until the capacity of the total system—especially of water resources—is assessed.

Excessive mineral content in soil or water can also be toxic, both to plants and animals, and in particular bore waters must be tested for fluorine, sodium, and radioactives. Nitrates are to be rigorously tested where children are consuming water and garden leaf products, and nitrate fertiliser used at minimal levels, or not at all in the absence of mulch or high organic soil content (20% or more humus).

Aluminium, boron, sodium, and manganese can be in over–supply at very low or high pH values, and only humus can buffer the uptake of these excess minerals. Aluminium in acid soil solutions damages roots, and high levels of manganese causes stunting and yellowing in plants. 0.5 ppm copper, or 10 ppm lead or zinc can stop root growth completely (Bradshaw and Chadwick, 1980).

A complex soil nutrient, essential to all plants for growth and enzymes, is phosphorus. It readily becomes insoluble in acid soils, combining there with iron or aluminium. In calcareous soils it forms insoluble calcium compounds. In arid areas, phosphates can be deficient except in humus, in forests, and in the silt of ponds. Manure from seed–eating birds has high phosphate levels. Correct inoculation of introduced plant species with phosphate–mobilising mycorrhiza may be essential to their growth. *Acacias*, eucalypts, legumes generally, pines, *Casuarinas*, and even garden crops can benefit from the root associates that enable their roots to accumulate phosphorus from the surrounding soil. Phosphates must always be applied in small quantities, close to the crop.

Trace elements (zinc, copper) can be applied to soil (as sulphates), and 7 kg/ha of both zinc and copper sulphates added to alkaline South Australian soils enables pasture growth (and the carrying capacity of sheep) to increase by a factor of 40 times. 50 g/ha of molybdenum in more acid soils enables clover production. However, it is also possible to add micronutrients as foliar sprays, to infuse them into irrigation water at root level, to include them in slow–release pellets at root level, or to mix them in bulk soil amendments such as dolomite. Over–supply of these same nutrients will result in toxicity and health problems. No amount of guesswork can supplant careful and skilled soil analyses. Plant tissue from healthy garden plants should analyse about as in **Table 11.1**.

MINERAL SOLUBILITY AND pH; SOIL AMELIORATION

A general solubility diagram is given below for soil minerals; this is, in fact, a measure of the availability of specific minerals to plants. Important soil constituents (iron, cadmium, silica) show a range of solubilities with pH as follows:

- IRON: very soluble at pH 3–3.5 as limonite (yellow) Fe_2O_3, and at pH 7–8 as iron oxide (FeO), which reddens alkaline deserts.
- ALUMINIUM: very soluble at pH 4–4.5 and pH 9.5–10 as Al_2O_3; relatively insoluble over normal garden ranges.
- SILICA: slightly but increasingly soluble over pH 0–8, but then rapidly becoming more soluble up to pH 10 as SiO_2.

Iron and manganese (ferromagnesium minerals) are closely associated in soils, and show the same spectrum of deficiency with pH. We can often therefore ameliorate soils at the higher pH levels with the addition of simple sulphur, and restore iron, magnesium, and phosphate levels to plants if these are "locked up" (and test as being present). We seldom garden at pH 3–4, but if we do, we will need a fairly massive calcium input as crushed or burnt lime, or crushed shells, to increase the availability of nutrients.

In the deserts, the soluble aluminium and silica may be evaporated to the clay minerals allied to illite or montmorillorite soils. With all minerals, higher temperatures in water greatly increase solubility. Aluminium ores are usually formed at the lower pH values, and hydrated to gibbsite or bauxitic ores.

The carbonic acid naturally present in rain (and very much increased in rainwater as it infiltrates soils) removes potash from orthoclase in granites. In the plagioclase of white granites, calcium and sodium bicarbonates are similarly formed, or potassium and magnesium carbonates from biotite rocks (biotite, dacite).

FERTILISERS IN ARID AREAS

Fertilisers, apart from humus and limited animal manures, should be used sparingly. Excessive green growth can subject trees, in particular, to drought stress. Magg suggests a novel method of burying two plastic bags in the planting hole for valuable trees, provided

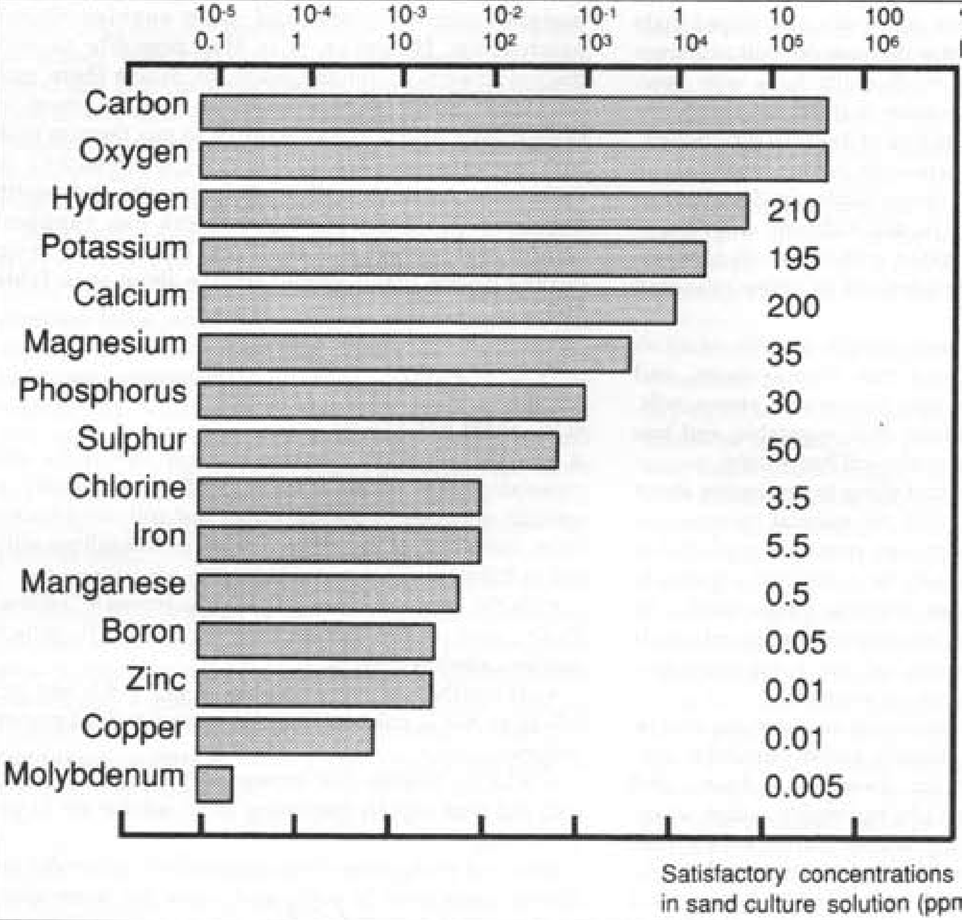


TABLE 11.1
Typical concentrations of mineral nutrient elements in plants, and concentrations in solution for satisfactory growth in sand culture. [After Bradshaw and Chadwick, 1980, *Plants and Soil*.]

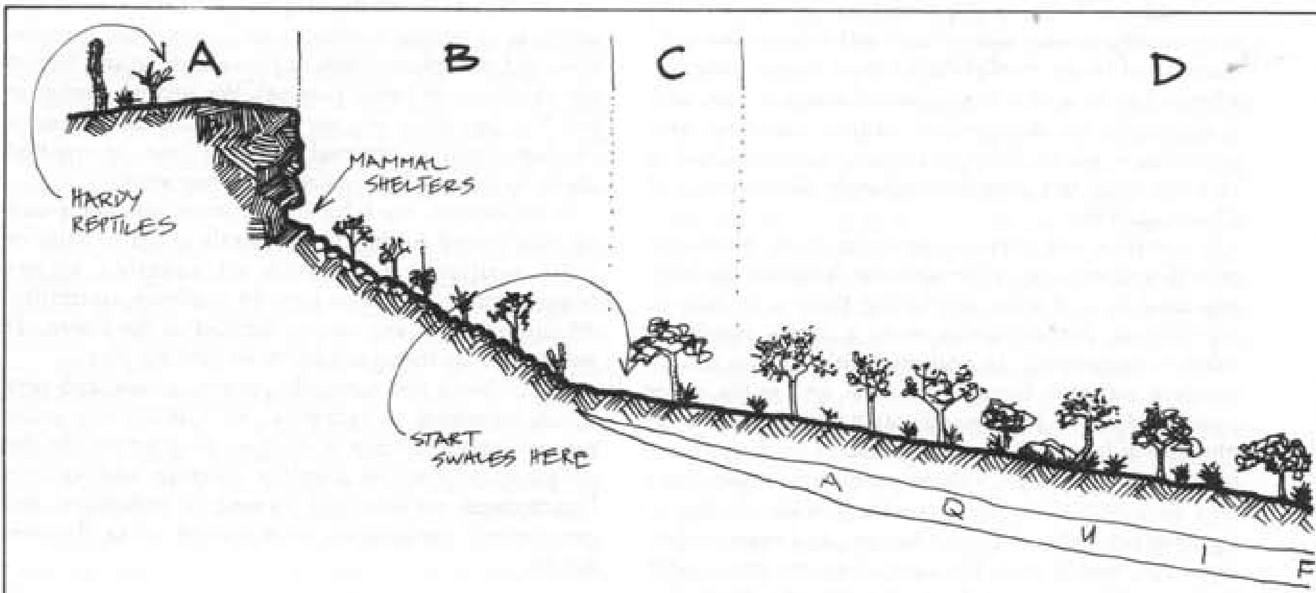


FIGURE 11.2
DESERT VALLEY PROFILE IN FOLD MOUNTAINS.
A. Hard lateritic or ironstone cap in plateaus; skeletal soils, long-lived hardy, woody plants.
B. Loose scree slopes; bunch grasses, hardy plants, some large trees if infiltration is good; coarse sediments; mammal and reptile shelters and burrows.
C. Outwash plains, sandy clays, fast runoff; will grow trees if swales are introduced.
D. Sandier infiltration and "flood out" areas. Trees can be as a scattered

with pin holes. These contain 0.5 kg of phosphate and slow-release pelleted fertiliser. These last the life of the tree (Magg, D. H., *The Potential for Horticulture in Central Australia*, CSIRO Horticultural Science).

Gardeners generally have had good results from shredded bark, manure, and leaf nutrients as mulch, with compost below this, and some sulphur added if pH is high. Others have developed pit composting with continuous mulch layers above. An excellent system where salt in water is not a major problem is to combine a permanent compost pit with drip irrigation from a small sprinkler, or a smaller humus pit with a jar for watering (**Figure 11.69**).

In dunes, phosphate, ammonia or guano, and zinc give good results (for trees). Ammonium sulphate is also used. Sewage waters have everywhere given good results with fuelwood trees (salt content must be checked for, as water gains in salts 300 ppm on its way through towns). Sewage lagoon walls are excellent tree sites, as are raised islands in the lagoons. Shallows grow lotus and water-lily. One feature of such lagoons is the large munber of trees that are bird-carried, as it is of waterholes generally (many seeds are defecated or regurgitated near water).

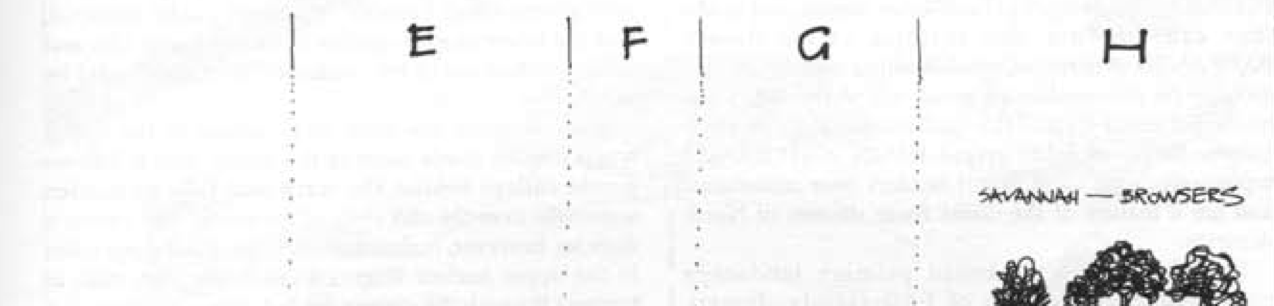
Most people do *not* add potash, as these salts, and sodium, chlorine, carbonates, calcium, boron, and magnesium may be plentiful in many arid soils, but the best advice is to get thorough analyses of both soils and leaf before and after growing.

THE EFFECTS OF POISONS IN DESERTS

All persistent biocides should be sensibly banned from drylands, as it is the (missing) aquatic plants that break these down most effectively. Herbicides used on lawns will seep slowly to sandy watercourses and down them for miles, travel up and down on groundwater, and kill thousands of plants over time. Water movement in soils is slow, and deep sands do little to offset poisons. Thus, natural remedies are a high priority for deserts and all fragile ecosystems. We should out-think, not poison out, any species that promise to trouble us, as most weeds provide biomass or mulch.

California is in very deep trouble with its groundwater supplies after a 40-year chemical orgy, and many Californians die of these poisons in their water. The few nearby swamps and lagoons are being wiped out, as are the trees near Alice Springs (Australia) where lawns are developed along with their poisons.

The position of settlement, and the disposal of sewage must be carefully assessed in arid lands (including arid islands). In Israel (*New Scientist*, 13 Oct., 1977) sewage and agricultural pollution rises through the sands in summer, and nitrates can be included in bore water pumped for domestic use. Winter rains again carry pollutants down, and they must then be kept clear of the water pumped to resevoirs. As many desert waters already have high levels of dissolved salts, any additional stress from nitrates may cause kidney malfunction. Some 47% of Aboriginal outstation people using bore water do in fact suffer kidney damage, consequent high blood pressure, and excessive intercellular water (a form of dropsy). It is easy enough



savannah, thick grasses after rains; stick-nest rats and mound-building birds.

E. River deposition of silts; many burrowing reptiles and small mammals; large trees with deep roots, figs, casuarina, river trees (cottonwoods in North America, redgums in Australia).

F. Sandy river bed or wadi; a fringe of dense large trees and vines if ungrazed.

G. Resistant rocky cliffs; can be springs; adapted figs, hardy trees.

H. Dry rocky hills, scattered shrubs and grasses after rain.

to go wrong in desert, and to put whole populations at risk; water in particular must be subject to frequent analysis for pollution and salts, and deep bore or well waters rigorously tested for excessive mineral and radioactive pollutants.

11.5
LANDSCAPE FEATURES IN DESERTS

Occupied and fire-managed arid lands present a total mosaic of vegetation, with very different changes obvious to the traveller. To "read" such a landscape mosaic, a designer needs to note:

• PROCESS: whether wind, water, or infiltration is active locally.

• ROCK AND SOIL TYPE: these decide local response to process and produce characteristic landforms.

• ASPECT: even slight shading by hills changes opportunities and promotes growth.

• FIRE FREQUENCY, and the time since the last fire.

• THE DATE OF THE LAST HEAVY RAIN: (more than 12 mm) which may have been the trigger for a specific age-group of plants (recruitment of species).

In drylands, erosion landforms are both more significant, conspicious, and more numerous in type than in humid areas. Extensive deserts may show ranges of MOUNTAINS with complex long valleys and shear-sided gorges draining these. Isolated or grouped granitic domes (INSELBERGS) rise steeply out of the desert plain, and the complex SCARP AND PEDIMENT landscapes of fault-lines, mesas, and wadis (box canyons) are also features of the desert. BADLANDS of complex, eroded, softer sediments may develop on unconsolidated areas, and sharp-sided and much branched GULCHES (gullies) develop on steep slopes. Series of folds give a BASIN AND RANGE topography over most desert borders near mountains, and are a feature of the Great Basin deserts of North America.

True desert has the broad primary landscape pavement classification of ERG (sandy desert), HAMADA (rock and boulder pavement), and REG (gravel surfaces). Of these, erg is further broken down into dune types and formations, some of which may lie over the reg or hamada base. Reg is generally taken to be an area from which sand and silt has been removed. Erg is composed of SANDPLAIN as near-level sand sheets over various substrates (also called sand fields) and dunes of several types.

In total, desert landscapes are angular, and actively eroding. Humid areas, and especially those clothed with grasslands and forests, have softer and more rounded outlines, with rare cliff faces at recent fault-lines or shorelines (**Figure 11.2**).

The lower slopes, basins, and playas (pans) of overgrazed and eroded drylands need attention, as do the dry river beds and aquifers that lie below the surface sediments. For this reason, and because a very scattered literature exists on desert strategies with respect to specific landform types, I have tried to assemble here a set of strategies suited to specific sites and landforms (**Figure 11.3**).

SCARPS AND WADIS

Wherever periods of uplift, or scarps of faults fracture desert peneplains, long cliff-lines (some running many tens of kilometres) stand above the lower erosion surface. While these uplift scarps are also visible in humid lands, in deserts they remain less softened, and develop characteristic profiles. These profiles, angular and essentially simple, will quickly emerge from the rounded hills of faulted humid areas once the vegetation is cleared and desertification sets in, as it has emerged in country cleared of trees and eroded in the 1920's in South Australia.

The process develops as per **Figure 11.4**. In true deserts, the profile is typically as per **Figure 11.5** (scarp section above and wadi plan below). Usually, the scarp face is fairly straight or only gently curved, and the wadis are at near right-angles to the scarp face. Within the wadi side, valleys leave again at near right-angles to the main valley; the pattern is that of parallel fault weakness and compensating joints in the rock.

Complex box canyons (wadis ending in cliffs), mesas (isolated pieces of the main scarp), and buttes (cut-off scarp sections) make various scarp-lines. Scarps are capped (the upper erosion surface) with durable ironstones, hard sandstones bands, ferricrete, or silcrete crustal material. Cliffs and scarp faces are generally of softer, sometimes bauxitic (alumium oxide) material, and the lower erosion surface is covered with silts and sands washed out of the wadis and later distributed by winds.

When it rains, the hard rock surface of the upper scarp surface sheds most of the water, which follows gentle valleys behind the scarp and falls as sudden waterfalls over the cliff ends of the wadis. Just before it does so, however, turbulence may scour out deep holes in the upper surface (**Figure 11.6**). Water may rush in torrents through the system for 3–4 days after rain, and the volume discharged largely depends on the catchment area.

A curtain of water, or rills, may fall along the whole scarp (there is usually a downslope just before the cliff) but this is a much more ephemeral flow. Nevertheless, over time, this curtain of water or cliff-base seepage may partly undercut the soft scarp, and **Figure 11.5** shows one of these scarp-base caves in the profile.

Like the cliff itself, the notch at the base can be very large (tall enough to take a 6-storey house) or very small (just large enough to give shade to a kangaroo or a sheep). Notches in the cliff face may be occupied by pigeons, owls, swallows and swifts, rodents, reptiles, and insects or their larval forms. Shade, like water, is a critical resource in the desert.

The wadi profile, or fair approximation of it, is also

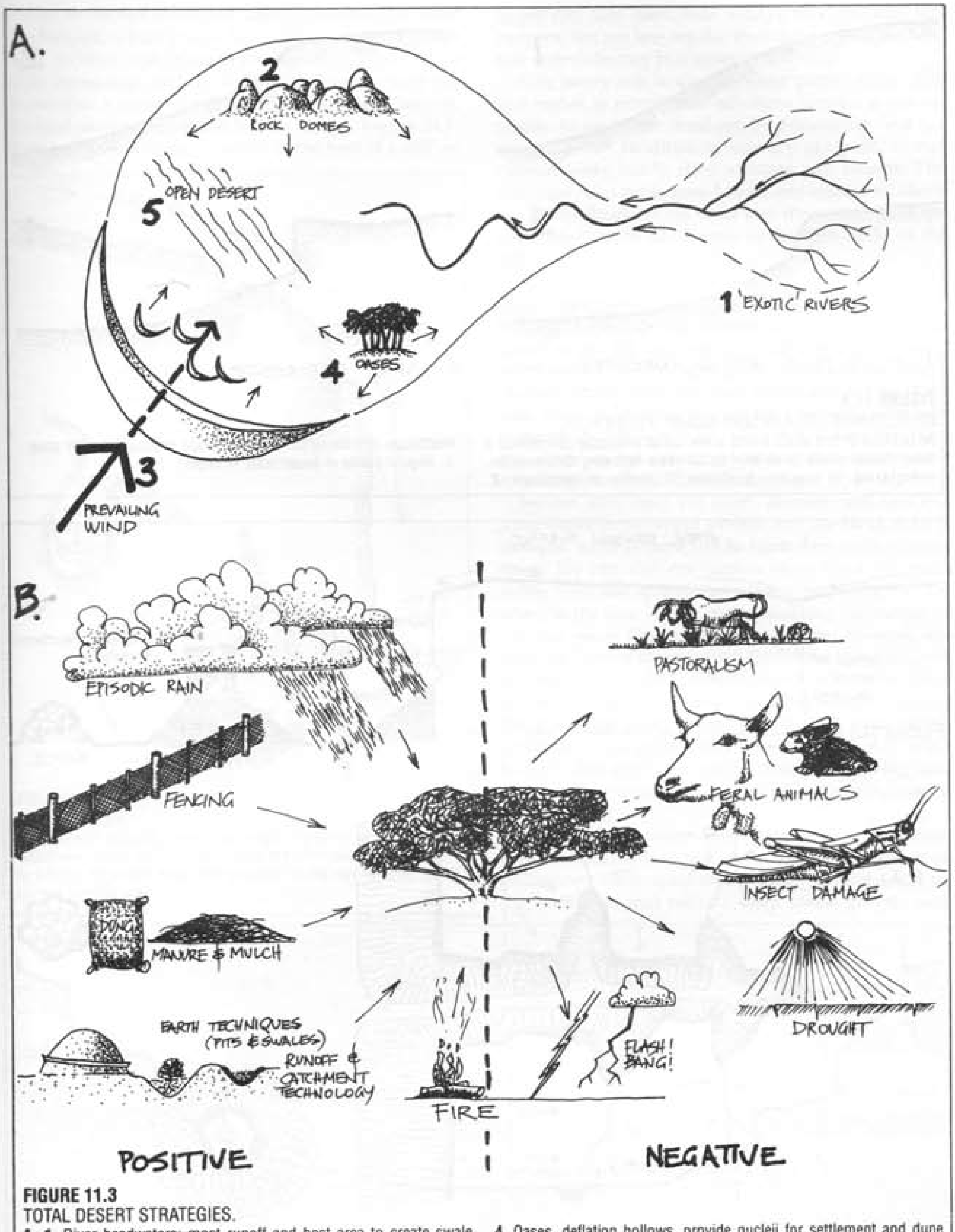


FIGURE 11.3
TOTAL DESERT STRATEGIES.

A. 1. River headwaters; most runoff and best area to create swale forests and generate vegetation downstream.
2. Inselbergs, scarps, and folds give many sites for runoff collection, some dams, foothills flood retardation and forests.
3. Upwind; pelleted seed, soil pitting, dune stabilisation protects downwind areas.
4. Oases, deflation hollows, provide nucleii for settlement and dune stabilisation.
5. "Flood–outs" and pans may yield crops after heavy rains; a general scatter of pelleted seed on the desert awaits rains.
B. Factors affecting desert stabilisation; investment and political policies have the greatest influence on these.

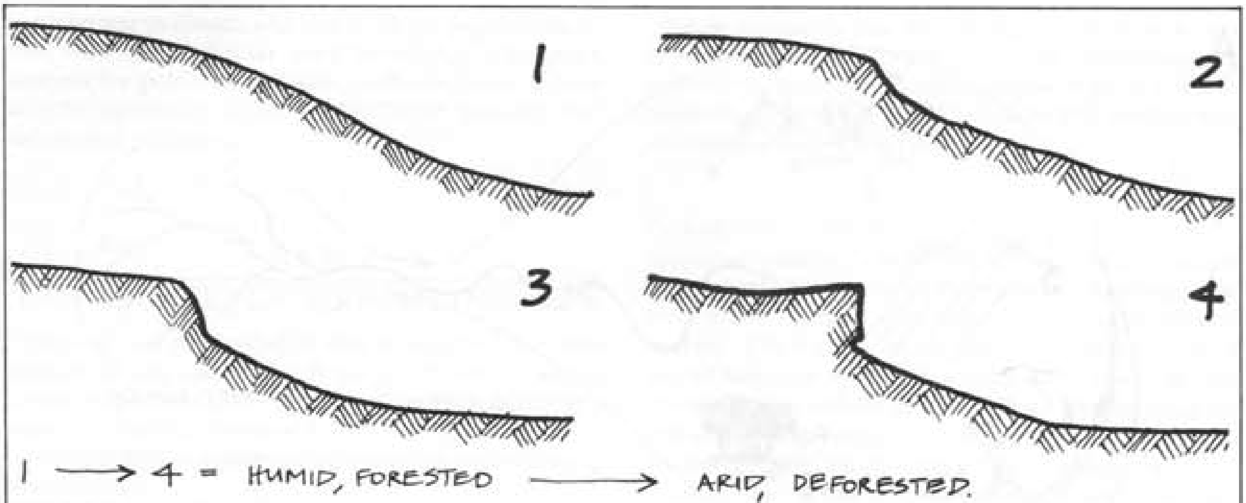


FIGURE 11.4
DEVELOPMENT OF A DESERT SCARP PROFILE.
An old fault or fold strata buried in the humid landscape can develop a desert scarp profile in as little as 50 years following deforestation, overgrazing, or erosion. **1**. Humid "S" profile of landscape. **2**. Headslope cliff develops. **3**. Scree slope develops at cliff base. **4**. Angular profile of desert scarp emerges.

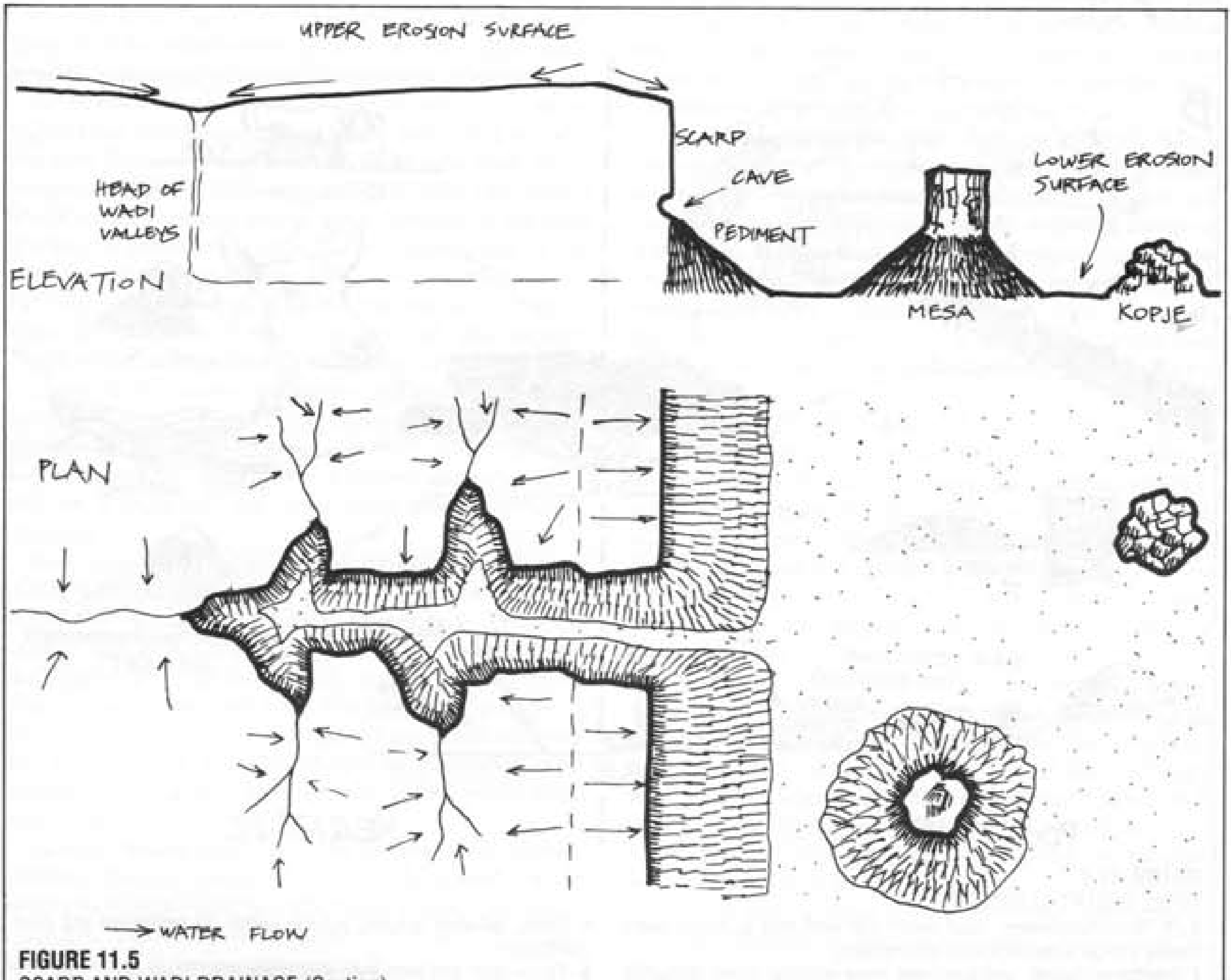


FIGURE 11.5
SCARP AND WADI DRAINAGE (Section).
Water from the scarp backslope falls over valley leads to wadi floors; settlement often locates on wadi pediments out of flood reach, or in large cliff notches.

found in incised sandstone valleys in semi-arid older landscapes, where rivers have cut down as the land rises. In these cases there is a valley floor (often with a river remaining), and the cliff is not a simple scarp but more often a set of complex smaller scarps and caves in bedded sandstones or mudstones, as per **Figure 11.7**. Caves still occur (large or small) at the base of a cliff, or in the cliff face itself. Side valleys may resemble box canyons, but are less regular than those of fault-scarps, and waterfalls may be a series of cascades.

After heavy rain in deserts, water pours off the cliffs and rushes as mixed mud-silt-stone torrents down the wadis. At times, the flood can be devastating, and has caused many fatalities in unwary campers, or has carried away badly sited villages and houses. The iron-clad rules are to keep houses and roads well above the valley floors, to cut them into the pediment of the scarp itself, or to site houses in the base caves of the cliffs.

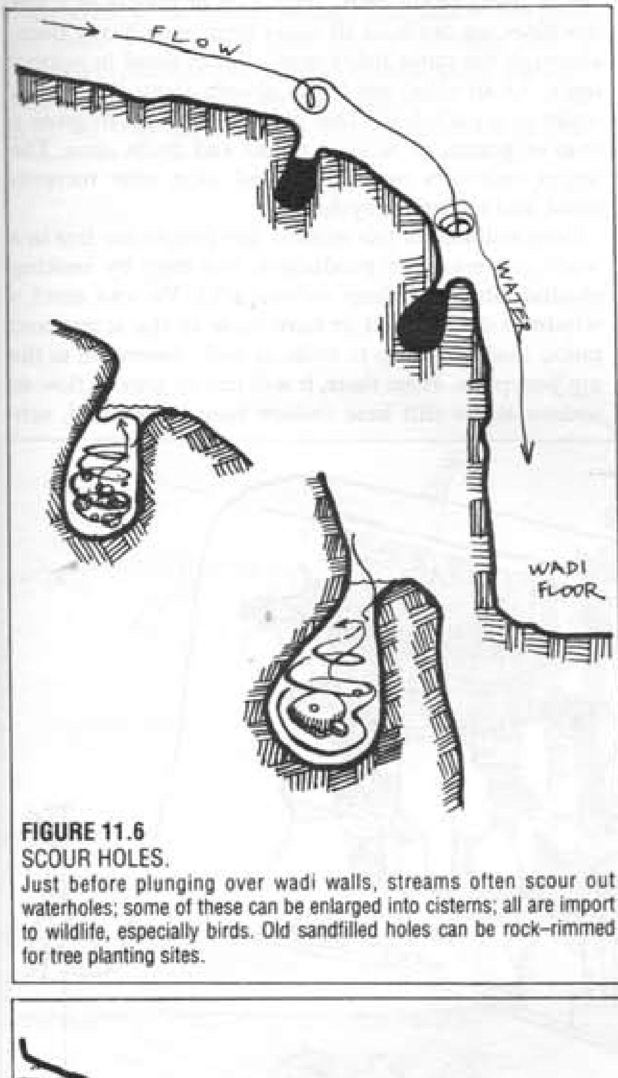


FIGURE 11.6
SCOUR HOLES.
Just before plunging over wadi walls, streams often scour out waterholes; some of these can be enlarged into cisterns; all are import to wildlife, especially birds. Old sandfilled holes can be rock-rimmed for tree planting sites.

Water Storage and Use in the Scarp Landscape

We can start on the top erosion surface to harvest and divert water. Up top, we can erect stone and cement dams across the generally gentle valleys of the upper plateau. These will hold clean water, and can be fitted with plugs or base pipes to let the flood water through more gently. Next, we can cut gutters across the scarp top above useful caves, and prevent too much water splashing over to our cave-house sites.

We can also clear silt from, deepen, and seal the scour-holes in the upper surface, and use these as tank storages. Some of these can lie *inside* dam walls as deep spots. We can also cut gutters away from the main valley head and spill all (or a larger proportion of) the water to the side valleys, again lessening the torrent in any one place. Once our high dam fills, however, we may still receive torrents over the headwater cliffs, and the only way we can further moderate the erosive effect of these is to make concrete or stone-cut chutes leading into excavated pools at the cliff base. All wells, pools, and dams will gather silt, however, and will need periodic cleaning. Dams can be cleaned by leaving base pipes open in alternative flows. Cliff pools self-clean by turbulence.

There is little hope of growing any but the very hardiest trees on the upper surface, except in crevices or deliberately constructed rock-walled containers. It is on the wadi floor that we find deep sands, gravels, and

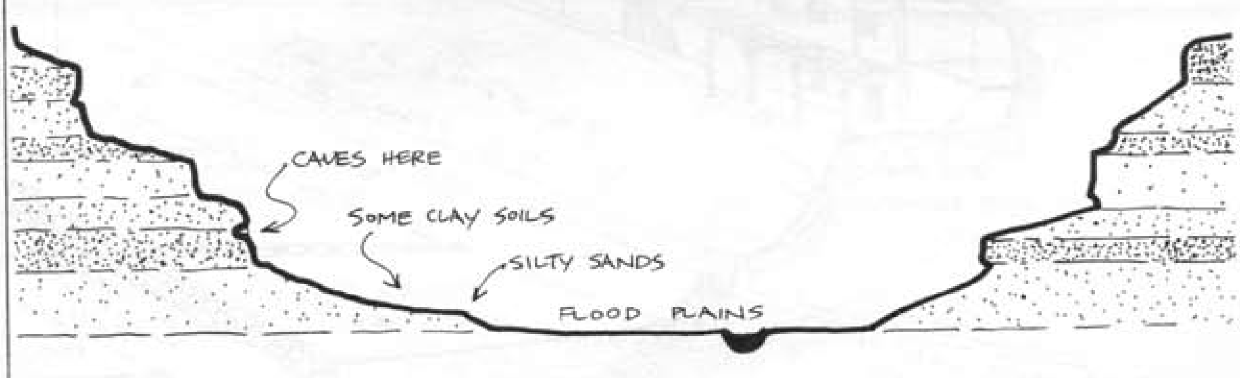


FIGURE 11.7
SANDSTONE VALLEY SCARPS AND CAVES.
Sandstones in semi-arid areas give a succession of scarps, caves, ledges, and a deep sand flood plain. These are more complex sites than true desert scarps, and are open to innovative design; wet seepages are common on lower ledges. Such profiles can arise in more humid landscapes of massive sandstones.

silts, and from there they spill out for a few kilometres onto the lower erosion surface.

In the wadi therefore, we need to erect strong rock walls across the floor, and let silt fields build up behind them. For minor wadis, the whole width may be dammed, and spillways cut in the pediment rock. In wide wadis, a central channel can be left open, and fields built to the sides (fed by side valleys). Once the flood spreads out on the lower plain, however, we can form very broad walls of earth and stone and soak it in to the fields so contained; these banks are best stabilised with unpalatable shrubs.

The most extensive wadi development studied to date is the ancient Nabatean systems of the Negev desert (Michael Evenari and D. Koller, 1956, "Ancient masters of the desert", *Scientific American* 194(4): 39–45) These have been in part restored, but there are also thousands of hectares of fields still abandoned.

The Nabatean systems hold 80–90% of run–off behind dykes in the wadis, and these are spread to lower dykes in the plains. The water is spread by highly coordinated flood and soak regimes to orchards. For every irrigated hectare, 20 ha of run–off surface are reserved as catchment. From the moment it begins to rain until the fields are soaked, the systems around Petra need close attention. In this area of the Negev, some rains fall reliably in winter every year.

The ideal is to let a minimum of water escape as run–off, and to absorb as much fresh rain water as we can in fields or silt beds. With a lot of people or a few machines we can hold all water from even heavy rains, although the outer fields may seldom flood in normal rains. As an ideal, we try to absorb about 0.5–1 m of water into each field. This gives us enough to grow a crop of grains, or to keep palms and fruits alive. The upper resevoirs can be released soon after torrents cease, and top up the system.

Even without all this work, a few people can live in a wadi and establish productive tree crop by seeking shaded sites and deep natural silts. We can erect a windmill over a well or bore close to the scarp, and pump fresh water up to tanks or rock cisterns on to the top peneplain. From there, it will run by gravity flow to houses at the cliff base (where they are shaded, safe

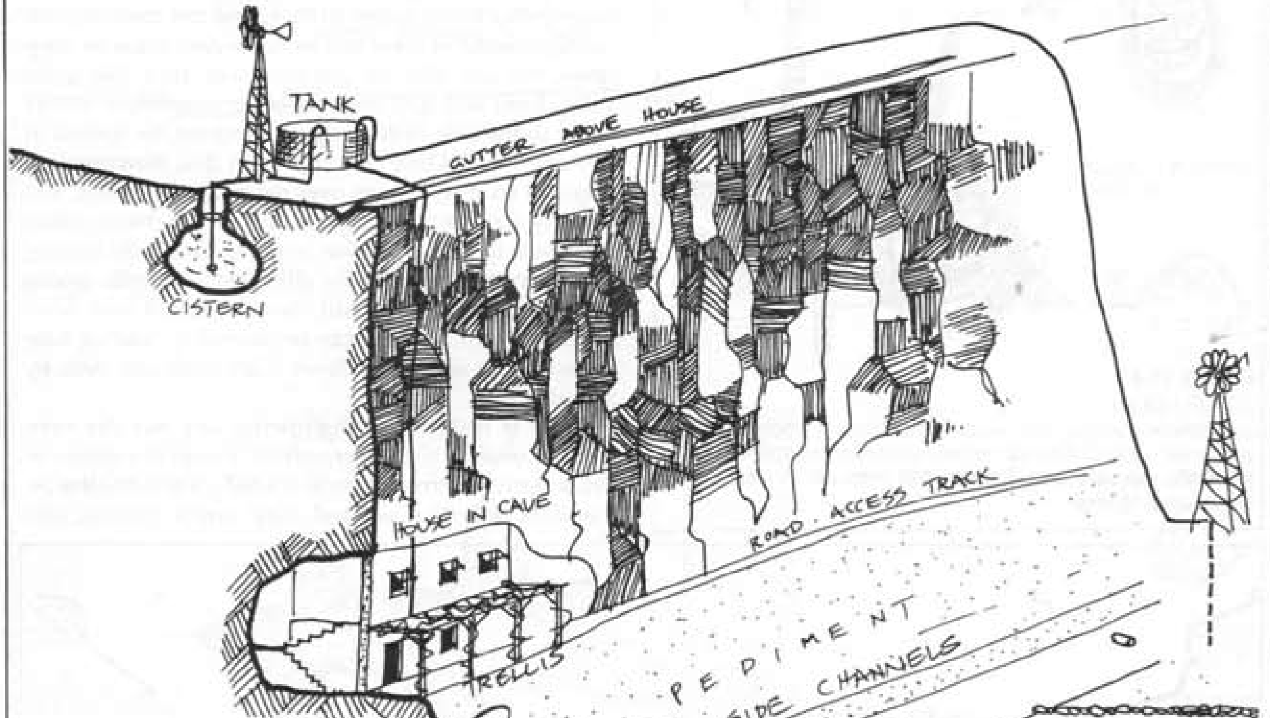


FIGURE 11.8
SCARP AND WADI ELEVATION.
Settlement, by–pass channels, fields, and central spill channel are features of wadi settlement. A windmill lifts fresh water to high cisterns above the settlement.

from flood, and can be in part excavated into the cliff base). **Figures 11.8 and 11.9.**

Fortunately, most peneplain crusts are formed over softer rock, so that the cutting of channels and gutters is fairly simple. There is usually a plentiful supply of rock for field walls on the pediment slope, and it is simple enough to dig a house notch if none exists. It is even easier to dig small animal shelters and pigeon nest sites, and these also form a food source. Fencing, too, is minimal in that box canyons can contain many hectares, most are bounded by steep cliffs, and have only a single entry, so that both human settlements and animal compounds are easily defended or protected from feral animals or predators.

I believe that with modern machines, fencing, windmills, and solar panels or photovoltaics we could creatively occupy many wadi systems (on a modest scale) that are now just grazed or neglected, and plant a desert forestry system.

Large trees already grow in most wadis, shaded and protected by the cliffs and immune from sand blast. By restricting hoofed animals many more trees would grow; overgrazing is the most obvious plague of arid lands. There is a wealth of detailed work that can be

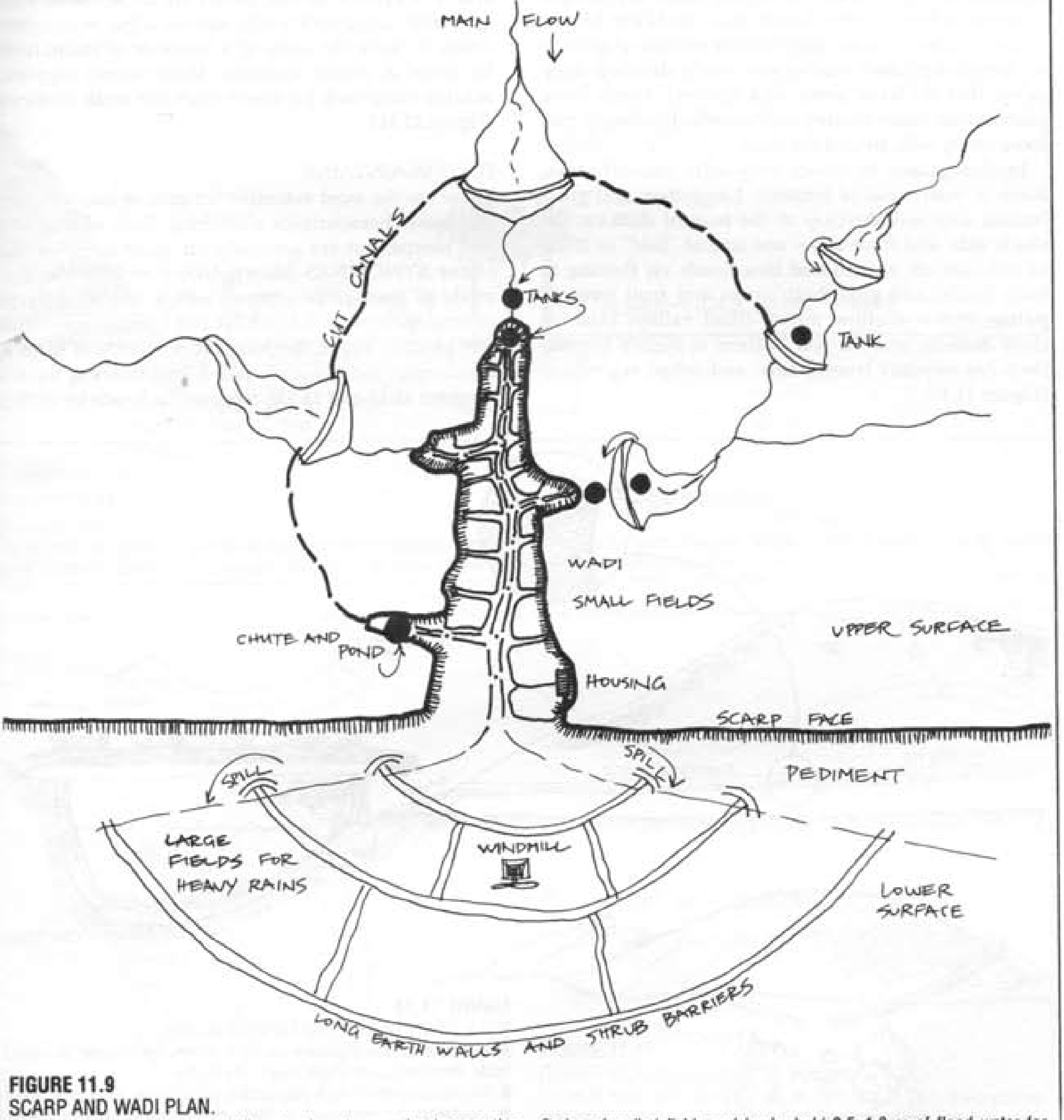


FIGURE 11.9
SCARP AND WADI PLAN.
Plan of some settlement modifiers to desert scarp landscape; the dams on the upper surface act as retardation basins for heavy rains. Series of walled fields and banks hold 0.5–1.0 m of flood water for infiltration to trees and crops during rain episodes.

done in the complex wadi systems, with many special niches utilised, and a rich flora and fauna (in most deserts) to be preserved and encouraged. Just by increasing shade, crevices, and ramp–access water cisterns we can stabilise and support a great many more desert quail and pigeon.

Where grazing animals (camel, goats), have been removed or controlled, as in parts of South Australia, a dense *Callitris* pine forest has regenerated, and palm forests can be established.

RESIDUALS, DOMES AND INSELBERGS

Compared with wadi and scarp, these are simple systems indeed. Great domes such as *Uluru* (Ayres Rock) in Australia and many similar massifs of granitic or metamorphosed sandstones rarely develop deep caves (but do have some rock shelter), rarely have pronounced valley entries, and usually dip steeply into loose sandy soils around the base.

Inselbergs are, however, very solid run–off areas, some of many tens of hectares. Large trees and good humus soils will develop at the base of cliffs on the shade side, and if we allow one acre of "field" to 20 ha of rock run–off, we can lead base floods via fluming to such fields, and grow both crops and fruit trees or palms. A few shallow mulch–filled valleys exist on these massifs, and the soil in them is mainly humus; they can support trees, yams, and other vegetation (**Figure 11.10**).

Occasionally steep and shaded clefts present sites for rock dams, but for the main, partly sealed tanks and soil infiltration must suffice. The larger systems (100 ha or more) have often been occupied in historical times by careful and conservative peoples, usually as base camps for long range foraging after rains. Each one has a special charm, and very sensitive and restricted occupancy is called for, developing and protecting natural resources rather than attempting extensive systems.

Very small rock slabs (1–10 ha) present a useful area for a gutter and tank system, a hectare or two of trees, and a wayside house. Some of these have been "guttered" using rock walls, slab on edge, or concreted drains to serve the needs of a house or of steam trains for water in remote locations. Many would support a wildlife ramp–tank for desert birds and small mammals (**Figure 11.11**).

FOLD MOUNTAINS

These are the most extensive features in many deserts, and have characteristics combining those of inselbergs and scarps, but are generally far more complex than either SYNCLINES (down–flexed sediments) may erode to great canoe shapes, with a few river gorges cutting their way out. ANTICLINES may form great whalebacks, but in the long run a river will form on their spines and again produce a long valley in the hills (**Figures 11.12 and 11.13**), faced on each side by cliffs or

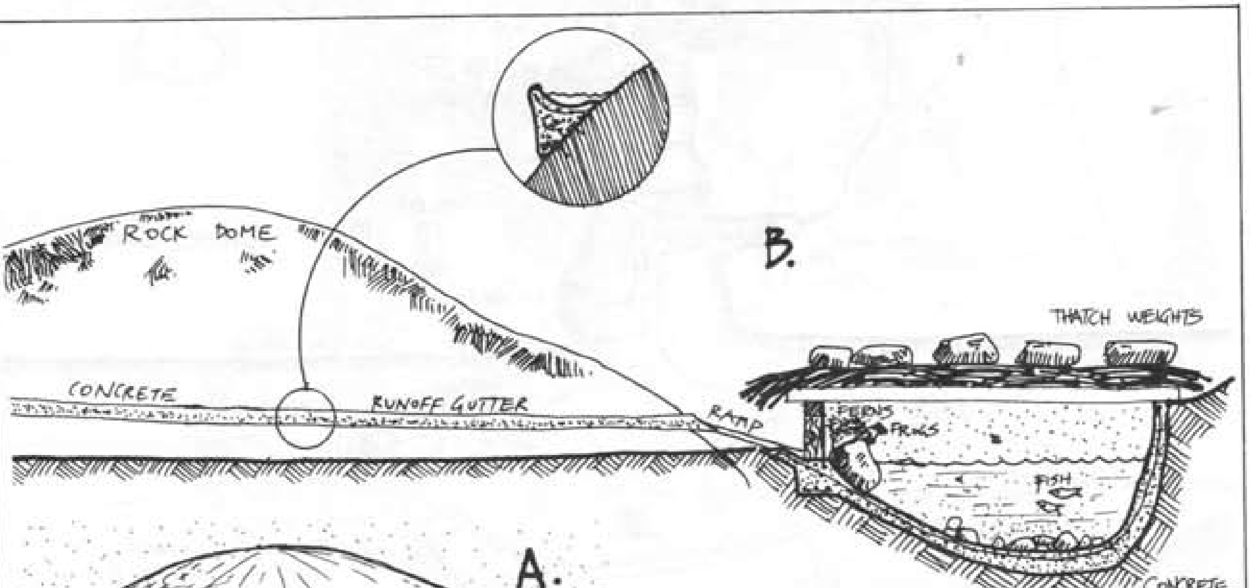


FIGURE 11.10
ROCK DOME WATER LED TO VEGETATION.
A. Concrete or stone gutters on bare domes lead runoff to walled fields, the latter about 1/20th area of the dome.
B. Simple concrete or rock slab gutters gather water from rock dunes or inselbergs for infiltration to fields, or storage in cisterns. These small tanks have access ramps for pigeon, quail, small mammals, and/or frogs. Thatch retards evaporation and excludes large animals.

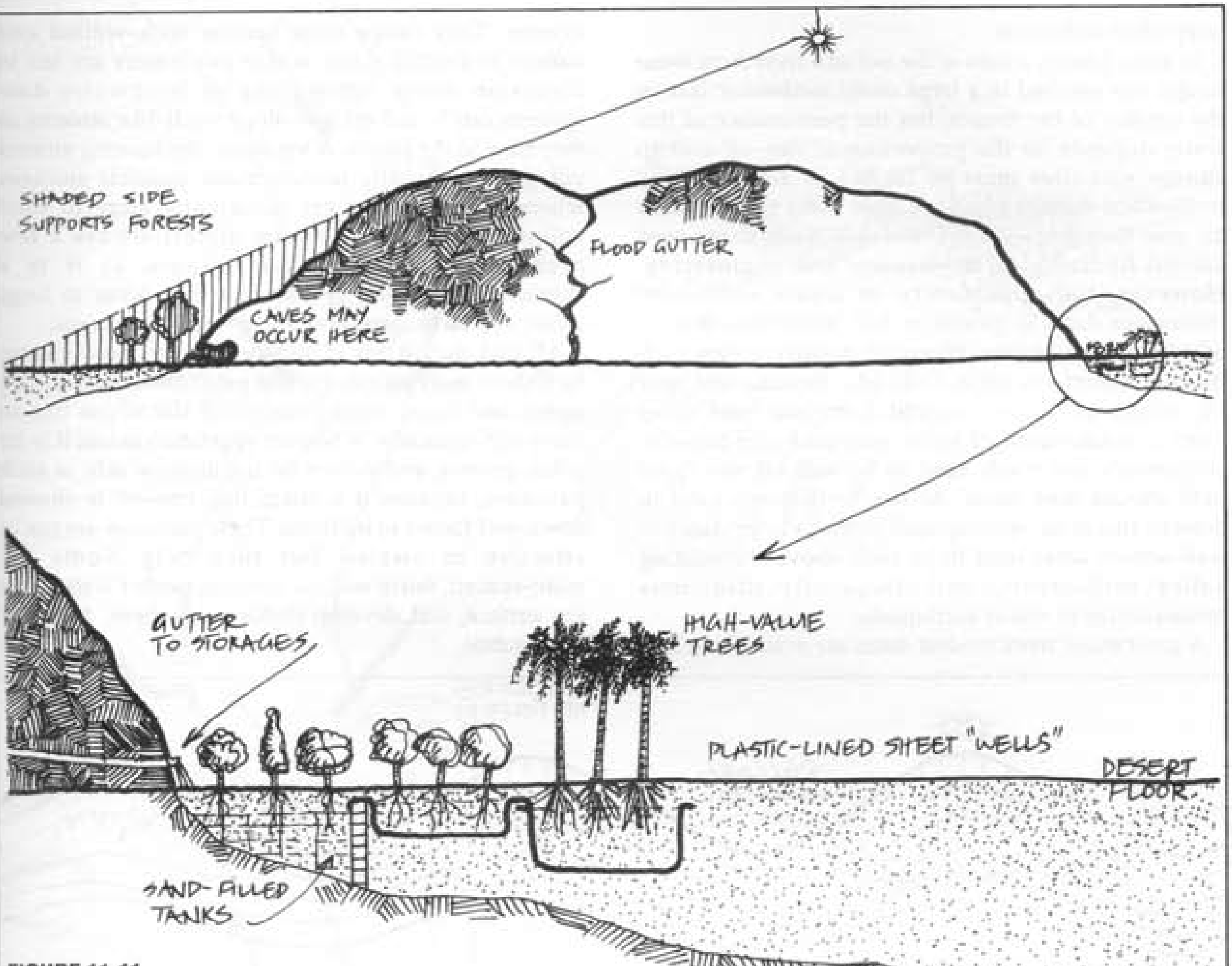


FIGURE 11.11
INSELBERGS.
These massive domes of granite or metamorphic sandstones are the least common dryland hill landscape; they at times occur in series separated by great fissures. While runoff is assured, sandy soils require cautious use of water.

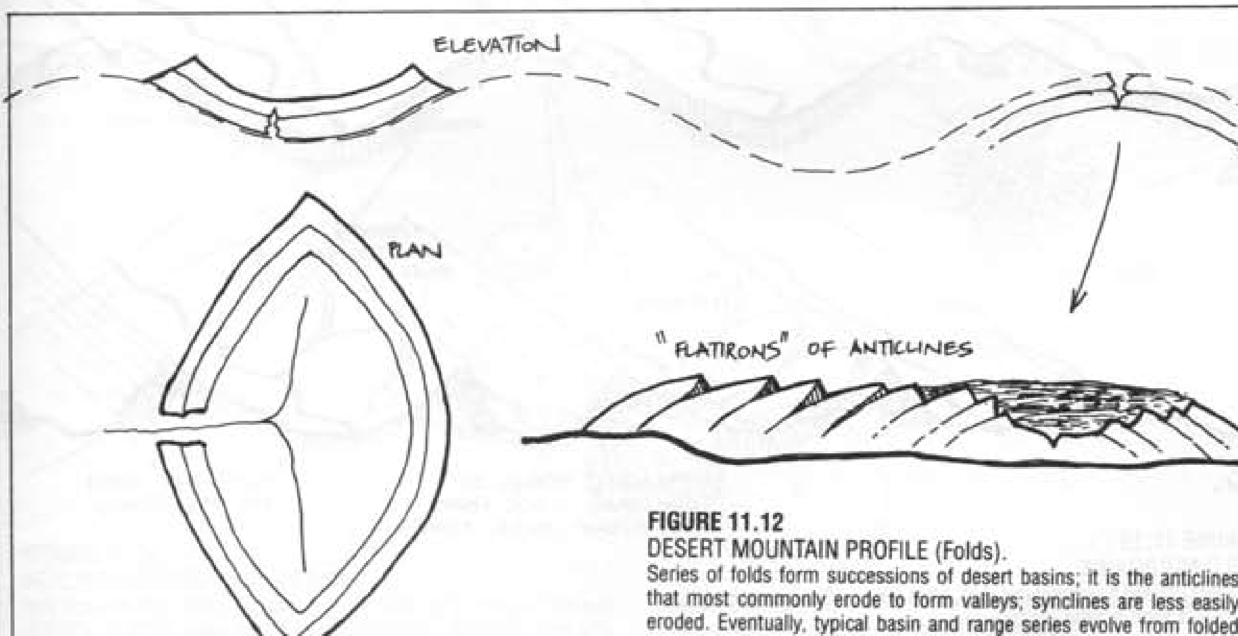


FIGURE 11.12
DESERT MOUNTAIN PROFILE (Folds).
Series of folds form successions of desert basins; it is the anticlines that most commonly erode to form valleys; synclines are less easily eroded. Eventually, typical basin and range series evolve from folded series. See also FIGURE 11.19.

steep tilted sediments.

In many places, a dam at the exit of a river from these ranges has resulted in a large ovoid freshwater lake in the interior of the ranges, but the permanance of this water depends on the proportion of run-off area to storage area (this must be 20–30:1 in deserts). Thus modest and deep storages are more likely to hold water all year than large shallow storages. Such dams need careful hydrological assessment and engineering. However, the opportunity to create successful freshwater dams is greater in fold mountains than in other desert landforms. Wherever massive ranges back the fold mountains (as in Colorado, Nevada, and near Mt. Ararat in Turkey), foothill dams will hold water from a combination of snow melt and rain run-off. Settlements and roads need to be well off any flood path should they burst. As few settlements exist in deserts, this is an open option, whereas large dams in well-settled areas tend to be built above the existing valley settlements, with frequently disastrous consequences in war or earthquake.

A great many more modest dams are available in fold sytems. They range from narrow rock-walled exit valleys to foothill dams where exit waters are led to diversion dams. Some complex freshwater dam systems can be led off low-slope wadi-like streams as they flow to the plains. A vigorous day hunting around village sites usually reveals many possible storages wherever the ranges are sufficiently large to shed volumes of water. These are almost always a few permanent rockholes and streams, as it is a characteristic of fold sytems that they occur in large series, and have correspondingly large catchments.

All fold mountains of sedimentary or metamorphic rock show more or less marked palisades of harder rock series, and these usually run along the slopes like so many sub-contours. Wherever vegetation exists, it is far taller, greener, and denser on the upslope side of such palisades, because it is there that run-off is slowed down and forced to infiltrate. These palisades are not as effective as swales, but they help. Some are wide-spaced, fairly well on contour, project well above the surface, and develop striking tree-lines. Most are more subtle.

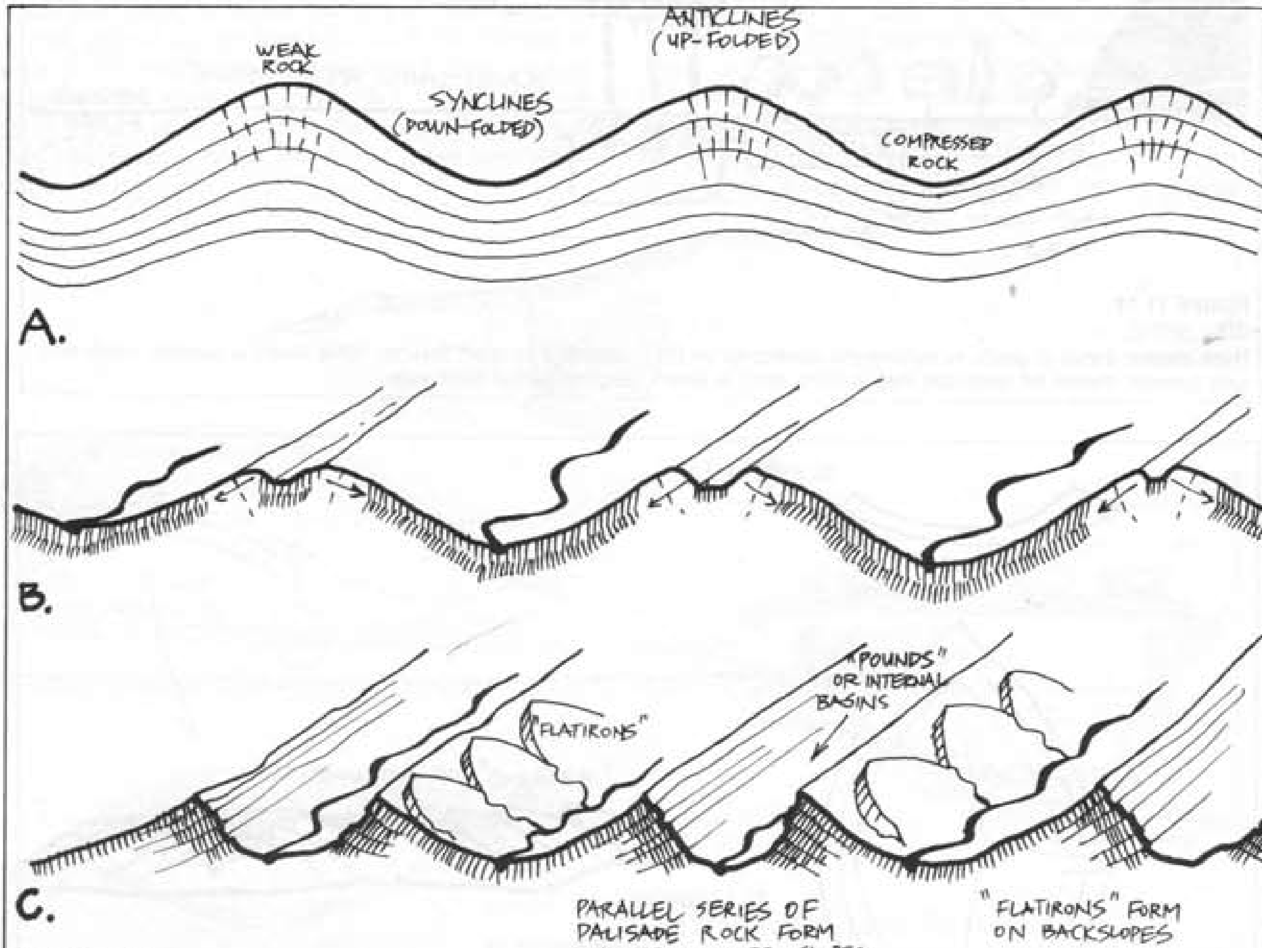


FIGURE 11.13
FOLD MOUNTAINS
A. Folds created by continental drift; often form inside coastal ranges.
B. Valleys form in weak anticline rock.
C. "Basin and range" landscapes.

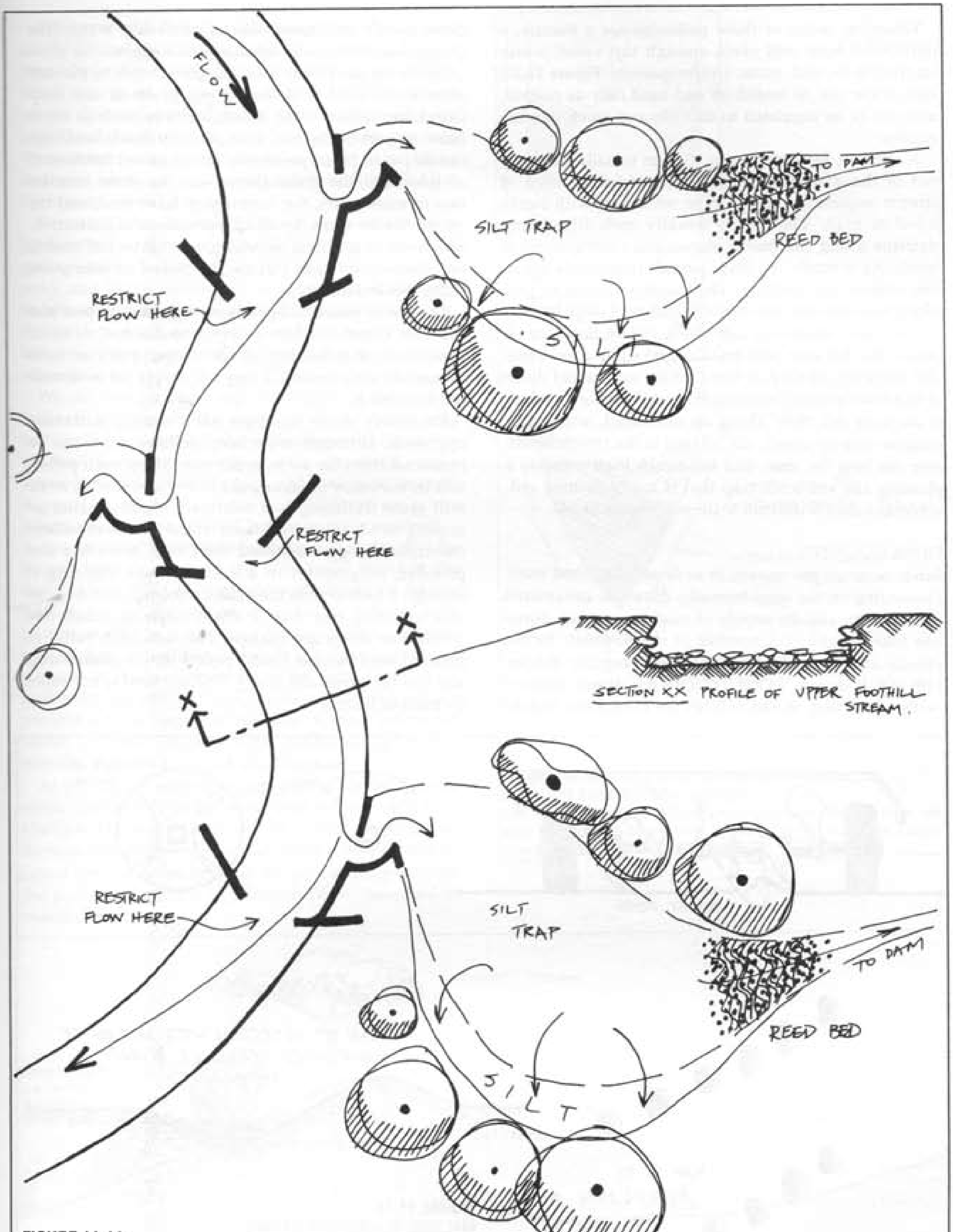


FIGURE 11.14
HEADWATER STREAM DIVERSION.
Fast streams from fold mountains can be "bled off" to dams or limonia (FIGURE 11.27.B) using rock or concrete walls, silt traps, reed filter beds, tree lines. This fresh water, in dams or swales, is used to aid desert forestry, or is infiltrated to soil storages.

Wherever series of these palisades are a feature, a horizontal bore will often enough tap sweet water trapped in the rock strata. Unlike quanats (**Figure 11.37**) such water can be sealed off and used only as needed, and can be be regulated to that amount taken into the aquifer.

A shallow, fast dry-stream system usually develops out of the upper foothill regions of folds, often of stream sequences only 4–15 m wide and with banks 0.5–2 m high. The bed is usually rock-filled, and detritus along the banks shows the extent of flood levels. As in wadis, the flood periods (when they occur) are violent and sudden. The boulders attest to this, along with the smashed lower branches of large trees.

We cannot effectively dam these violent flows, or we would fill that dam with boulder and silt in a few rains. But what we can do is to bleed off the torrent and divert it to a more peaceful contour flow, and thence to a dam. If we lead this flow along an oversized, wide, and shallow contour trench, silt falls out in the trench before ever reaching the dam, and the trench itself presents a planting site *and* a silt trap that is easily cleaned out, whereas a dam is difficult to de-silt (**Figure 11.14**).

DUNE COUNTRY

Sands occur on pavements, or as dunefields (sand seas). Depending on the wind intensity, duration, streamlines and velocity, and the supply of sand downwind, dunes can take up any of a number of characteristic forms, chiefly those of TRANSVERSE and regular ridges, OBLIQUE dunes, LONGITUDINAL dunes aligned with the wind, BARCHANS or crescents (horns downwind), and sand seas of curiously wave-like (rough sea) forms, with lobed advance edges.

Dunes on pavement (isolated dunes) can be planted after rains with a fast-growing grain or oat crop (sorghum, millet, some desert legumes such as moth bean) or yam beans, and a set of hardy *Acacia* seedlings can be put in place, preferably with a mixed fertiliser. If all goes well, the grains flower and the straw lasts for two or more years, the moth beans leave seed, and the small *Acacias* grow to effect permanent stabilisation. Species such as *Acacia victoriae* give copious leaf mulch, and desert yam bean pits can be placed in later years using this leaf mulch.

The whole process depends on a good rain, pest and browser control before sowing, and some minimal protection after sowing. A few larger quickset trees (tamarisk) may succeed if they are deeply set in or near the dune base.

Extensive dune systems need a very different approach, although even here, pelleted seed can be broadcast from the air to await rain. Many such pellets will be buried by sand, and if a heavy rain occurs, some will grow. Pelleting is a relatively simple matter of mixing seed, mud, fertiliser, some insect repellent (neutralised copper sulphate with lime, neem tree leaf powder, magnesite) in a stiffish mass, passing it through a mincer with the blades removed, and then on to a vibrating tray with a slight slope on which dry powder or dusts are shaken. The extruded "rolls" of pelleted seed become round pellets on the shaker tray, and can be spread out to dry. Pelleted seed is not eaten by birds or insects.

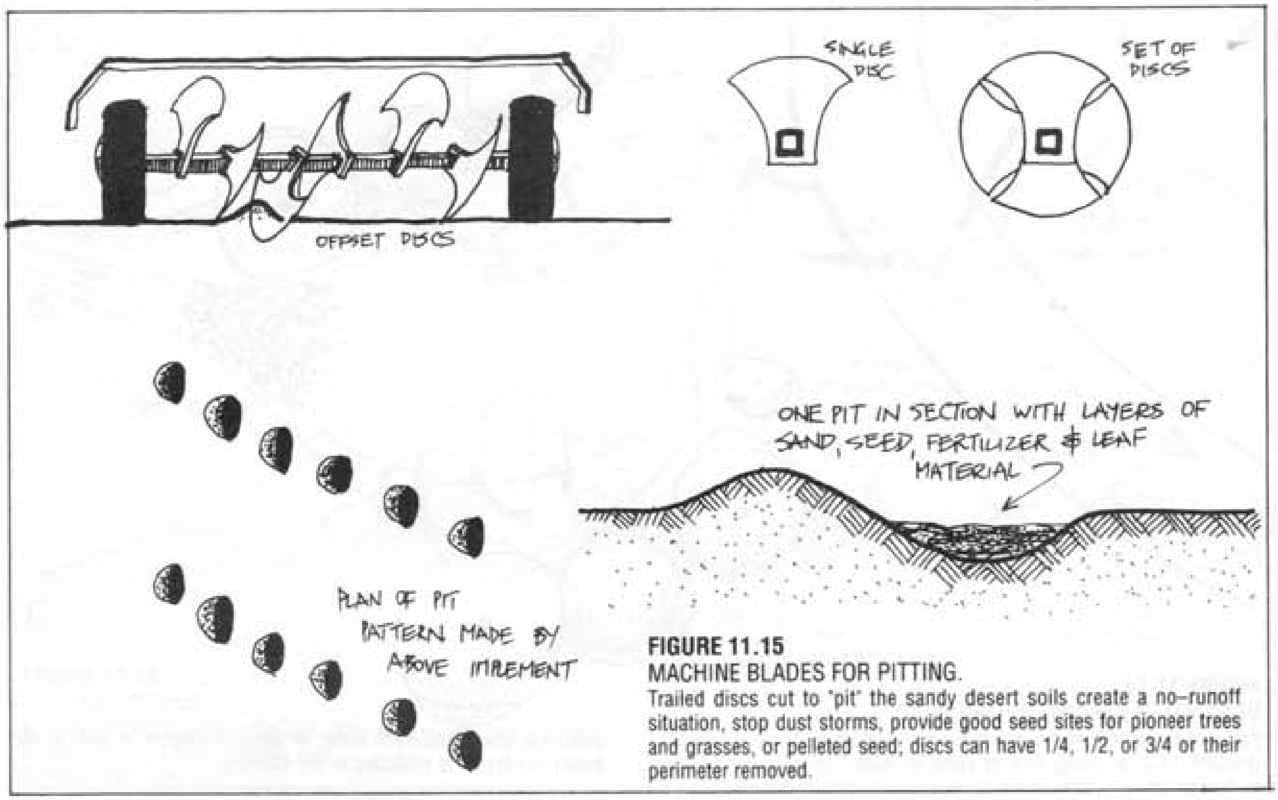


FIGURE 11.15
MACHINE BLADES FOR PITTING.
Trailed discs cut to "pit" the sandy desert soils create a no-runoff situation, stop dust storms, provide good seed sites for pioneer trees and grasses, or pelleted seed; discs can have 1/4, 1/2, or 3/4 or their perimeter removed.

Wherever rain flows or falls occasionally over bare sandy ground, PITTING is an excellent device, Here, a set of large discs with one-quarter section cut off or a small disc fixed to a wheel (**Figure 11.15**) is drawn across-country, and seed and fertiliser spread soon after. Seed, fertiliser, and sand blow into the pits, and these respond very well to subsequent rain. Many hectares of these pits have grown well near Alice Springs in Central Australia.

Severe dune "blowouts" on coasts need more intensive treatment, with hand planting of quickset grasses such as *Ammophila* spp., pelleted moth bean seed, and brush fences in 7 m squares to effect early stabilisation. Such fences are built from stakes 2 m long, driven 1 m deep, and with numerous bushy weaves between. Pits of seed and *Acacia victoriae* may succeed after rain.

We can look on dunes and dune fields as large water tanks. In deep sands, the surface to a few metres may have only 4% water, but as we dig deeper, at about 6 m we find damp sands, and at 40 m saturated sands. Some dune fields (with humus and dust particles) will support quite dense vegetation (50% cover) while others are almost sterile and lack basic plant nutrients.

Any traveller in vegetated deserts will notice that the largest trees (sometimes the only trees) stand in the dune ridges. This is apparent with dunes on harder pavement, or dunes on clay and a strong base pavement, but it is also true of coastal dune hollows and deflation hollows in sands. Dunes represent a resevoir of freshwater, much as the coral sands of an atoll hold rain which "floats" on the salt water, so dunes present a very large surface area of sand grains for water to adhere to, and rapid infiltration of rain is possible (**Figures 11.16 and 11.17**).

At the edge of large dune complexes, it is usual to see water rushes and sedges at the base seepage, and even shallow lagoons which are as much dune-fed as dune-dammed. It follows that dune on pavement or salted ground is the best site for permanent plantings; the problems are how to establish those trees, and to stabilise the dune.

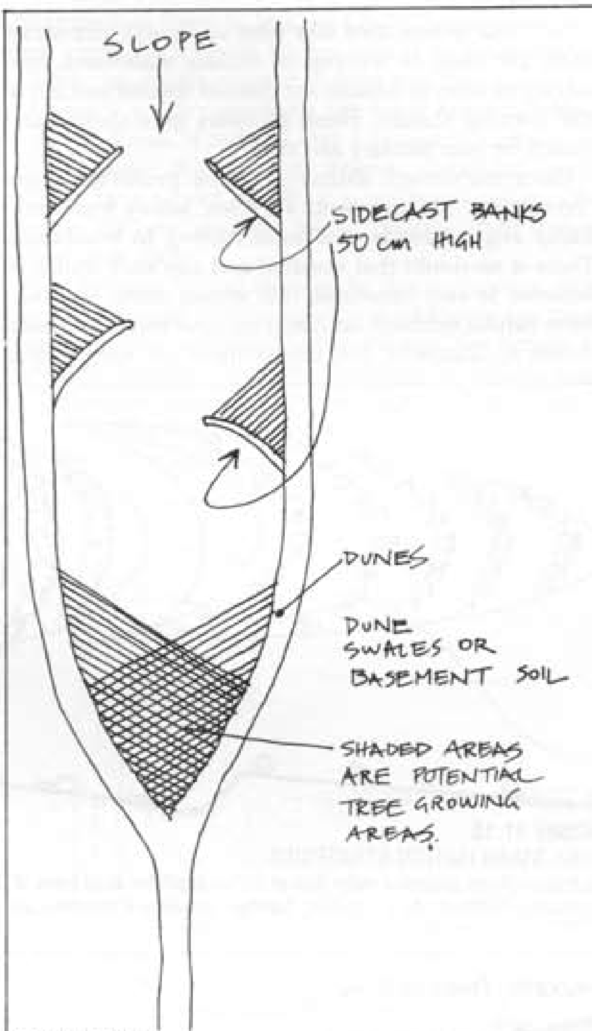


FIGURE 11.17
CHEVRON BANK IN DUNE SWALES.
Side-cast banks halt flood flow down dune swales; hatched areas will grow trees (parallel dune series); swales so chosen must have a slope "downhill".

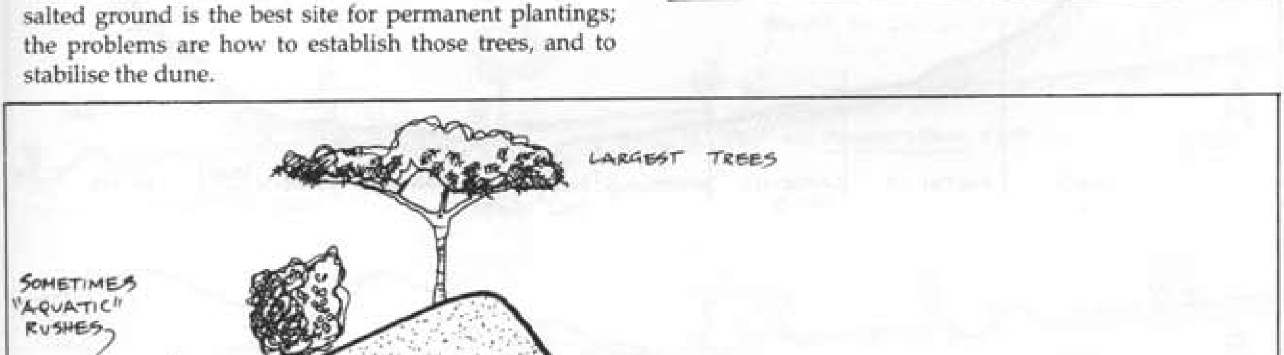


FIGURE 11.16
DUNES, LARGE TREES, FRESHWATER LENS.
Stabilisation by brush fences bring BARCHAN dunes to a halt; sand drift then creates an oval dune which infiltrates water and will carry adapted vegetation. Some sessile trees greatly aid this process (Acacia, Mesquite).

In China (where they take trees seriously), rice–straw mats are used as fencing or surface stabilisers, and advanced trees in baskets are planted (basket and all) in the matting shelter. These pioneers give shelter and mulch for later forestry and crop.

Once stabilised, dunes must be protected from "recreation" (devastation) vehicles, heavy browsing, badly aligned roads, and sand mining to windward. There is no doubt that sawdust and any such mulch in hollows is very beneficial; mill wastes (bark, sawdust) have helped establish an *Acacia sophorae* forest in coastal dunes in Tasmania, but unless there are such wastes locally available, other strategies must be undertaken. All plants in dunes benefit from nitrogenous fertiliser, phosphate, and trace elements, as old dunes are usually deficient in plant nutrients.

DUNE STABILISATION

Apart from the stabilisation of sand and silt surfaces by pebbles and vegetation, any "cementing" system will help. Water creates bonds between particles that call for much higher wind speeds to move the sand, as does salt (especially where dew is present, as salt is

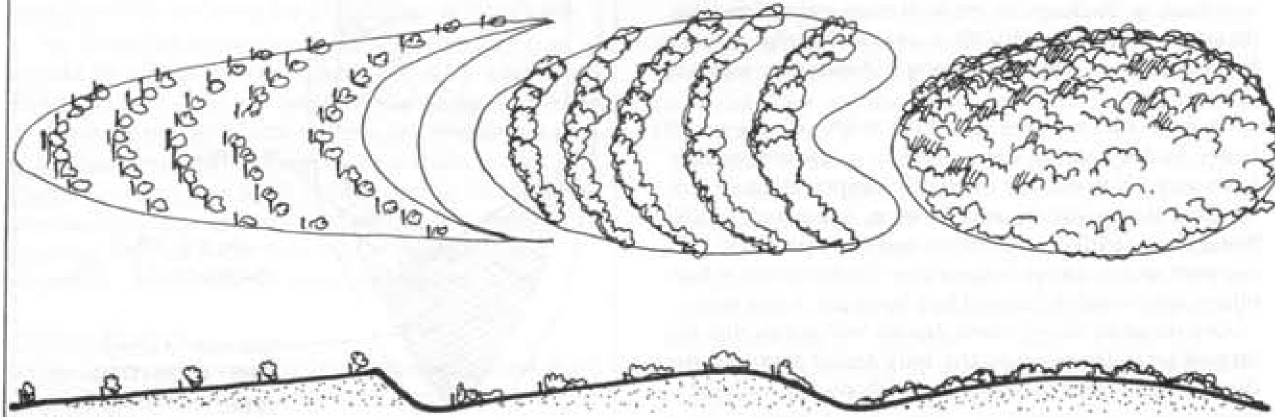


FIGURE 11.18
DUNE STABILISATION STRATEGIES.
Stationary dunes provide a water lens at 2–3 m depth for large trees, if moderately fertilised. As a travelling barchan stabilises it assumes an oval profile.

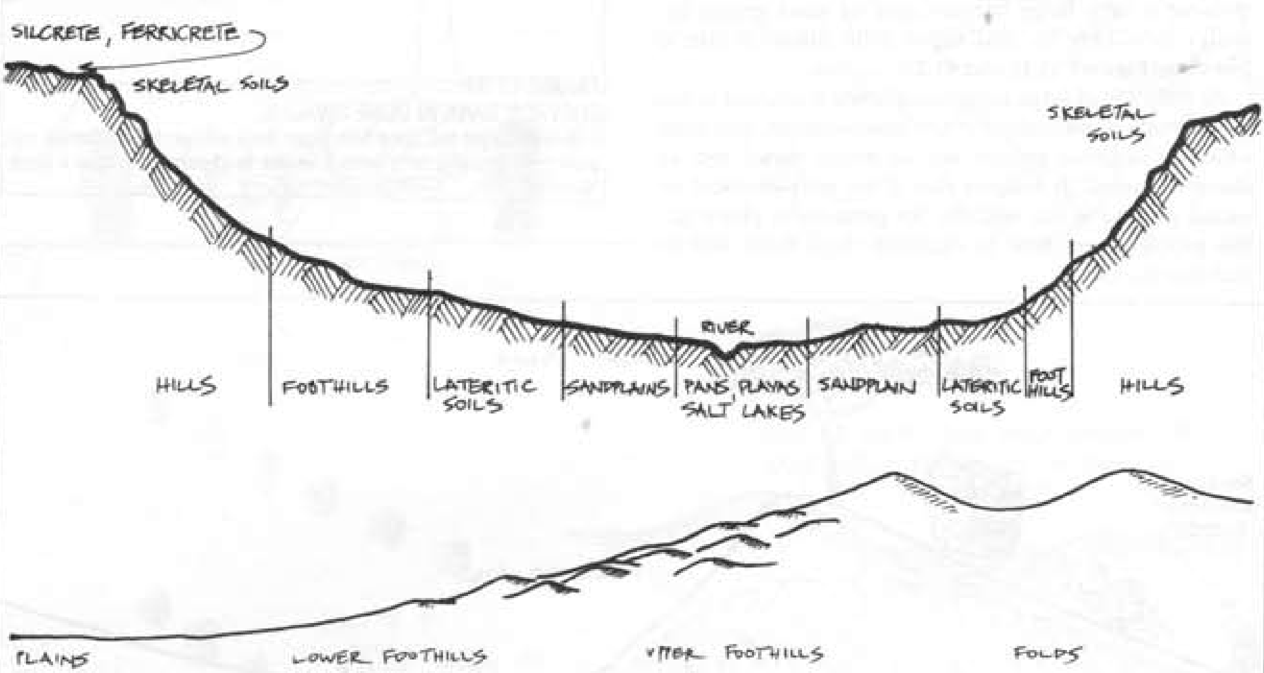


FIGURE 11.19
BASIN AND RANGE TOPOGRAPHY.
A. Classical profile in fold mountain series. Water conservation begins on foothill slopes and forests are generated downhill.
B. Complex foothills provide many sites for water storages and swales, limonia (see FIGURE 11.27.B).

hygroscopic or water–absorbing), or we can use tars, oils, or glues such as latex. Lichens, bacteria, fungi, and algal mats form naturally, as do salt crusts. Thus, no dunes form in some deserts where salt crusts or minute plants cement the surface of the ground. These often delicate desert crusts are critical to stability, and when hoofed animals, fast vehicles, or (worst of all) agriculture is brought into deserts, wind erosion may quickly follow.

Stabilisation in urgent cases can be effected by spraying tar oils, laying down pebble beds, or building brush fences 0.9–1 m high in parallel rows 7 m apart across the main wind direction. These fences must have wind gaps of less than 50% to drop sand out, firm posts driven every 3–4 m, and be combined with planting sequences for permanence. Temperature reduction of 12°C or so have been measured in the shade of fences. Moisture loss there is less, at 1.8–3.0% less than the open areas. Such fences are precursors to the planting of hardy perennials adapted to dune conditions.

As lethal soil temperatures are rarely formed below 15 cm in dunes, it follows that a careful placement of trees in holes this deep or deeper, stabilised from collapse by a woven basket or a cardboard collar, will prevent the new seedling being "cooked" until it can cast its own shade.

Any fertiliser should likewise be thinly placed at this time, as the rapid infiltration of water in rains can take it down below root reach. After the tree has spread a root web, however, more fertiliser can be added, and will then be taken up by the plant. Any plants pioneering the dune must be able to stand stem burial until the area is stabilised.

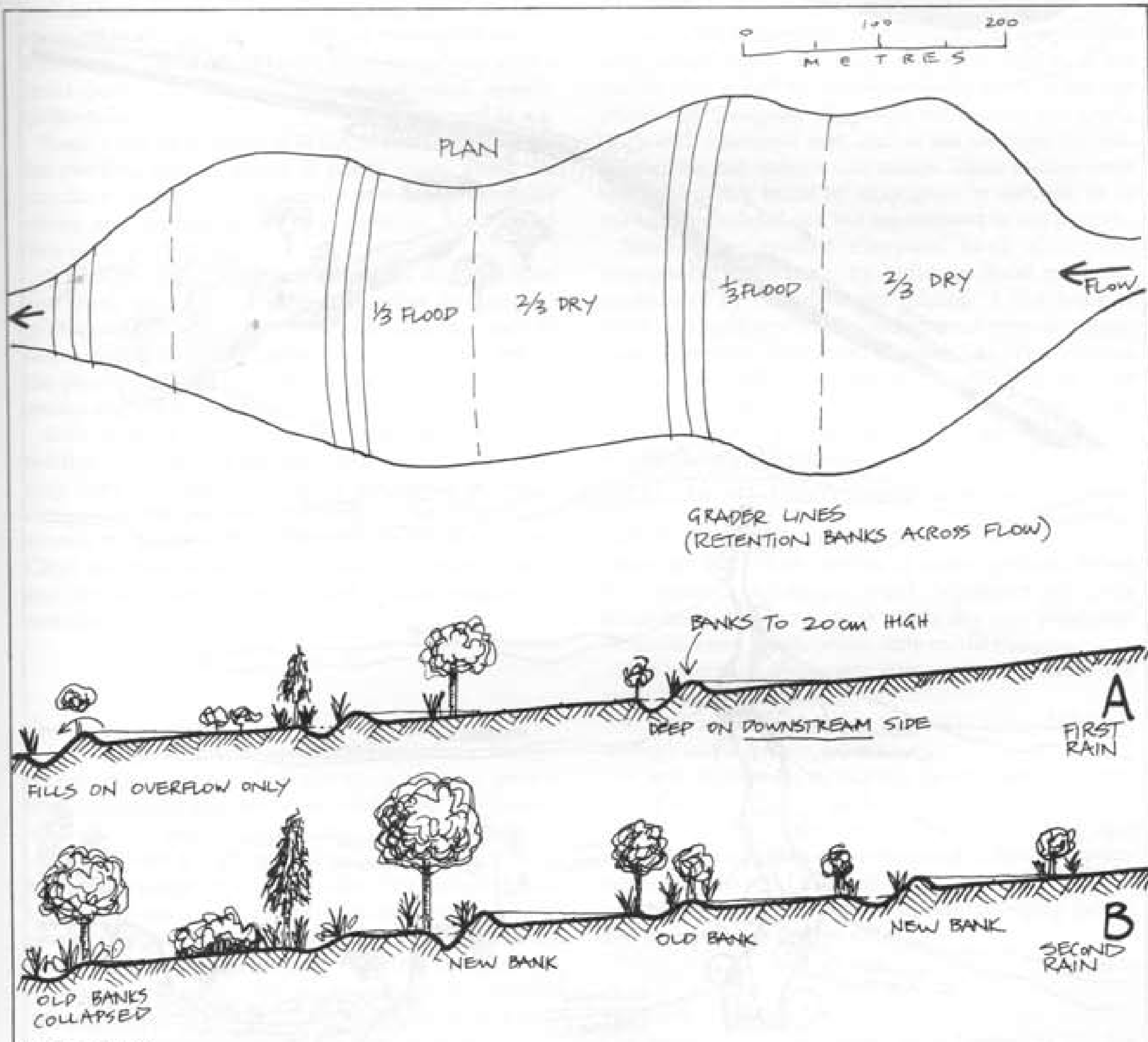


FIGURE 11.20
REVEGETATION OF SCALDS.
Clay ridges side–cast "uphill" aid infiltration and vegetative cover; as clay banks level out, new banks enable plantings to establish; circular or spiral banks can be made on large claypans; total revegetation may take 3–4 rains.

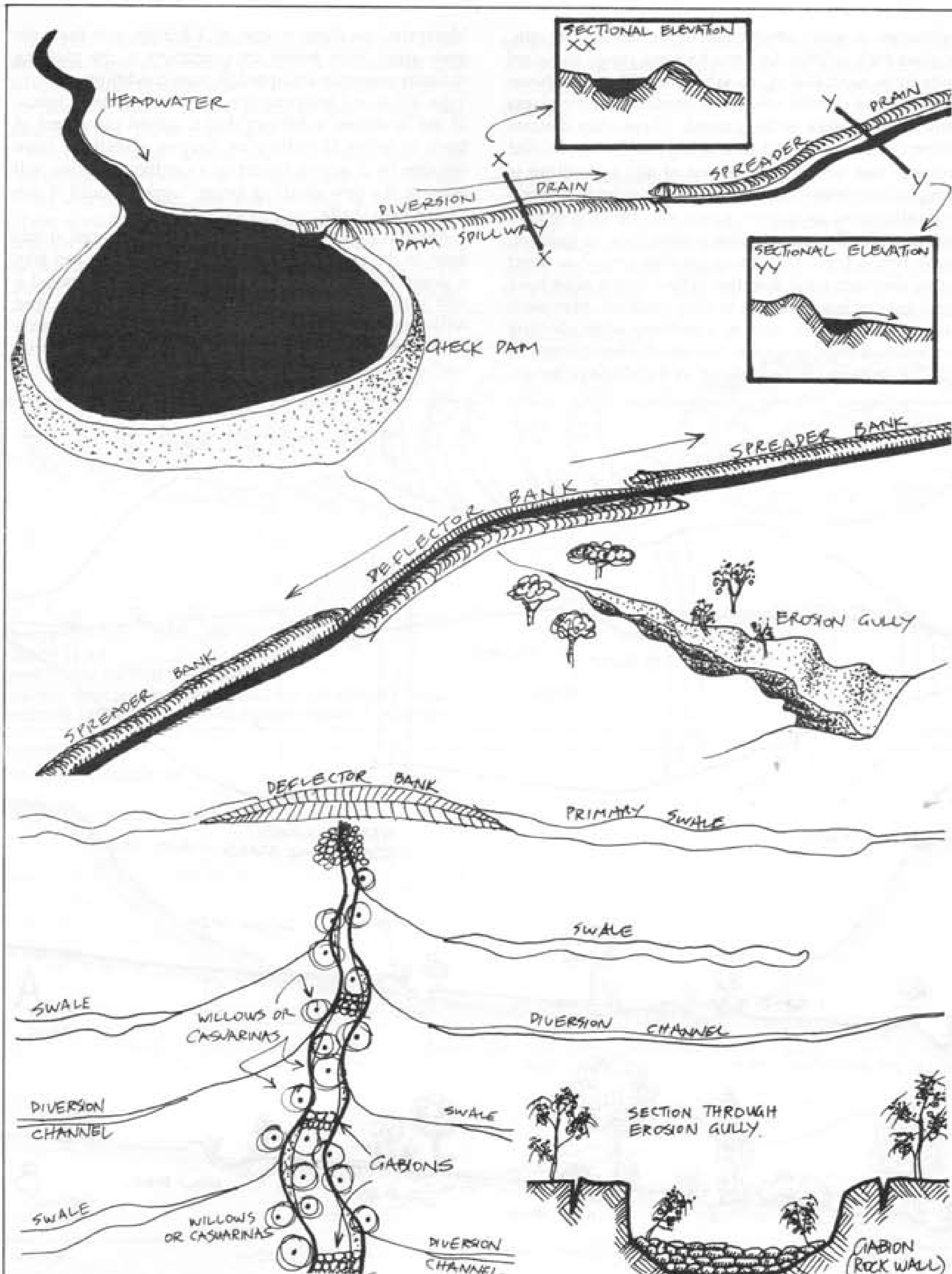


FIGURE 11.21
STRATEGIES FOR HEALING ACTIVE GULLY EROSION.
Small gullies can be filled, fenced, and planted. Large gullies need multiple strategies, including diversion of head waters, swales to hold water of side walls, gabions on gully floor, fencing, and tree planting. Spreader banks spread headwaters gently downstream.

Such strategies as vegetation stabilisation do not apply to hyperarid zones, where only fences and sprayed surfaces can operate to hold sands from roads or settlements (which would be rare in such landscapes).

DEPRESSIONS AND BASINS

Low flat areas or near-circular depressions are called (on the large scale) TECTONIC BASINS. Next in order are fairly large DEFLECTION (WIND) HOLLOWS, and smaller depressions with flat floors are called PANS. Some of these are clay-based evaporation areas and are called CLAYPANS, others are salt-based and are called SALT PANS. Clays can be treated with gypsum to increase their capacity to infiltrate water, or with sodium carbonate or bentonite to seal them where they are to be used to store water. Natural montmorillinite or illite clays swell and form impermeable surfaces after a short period of rain, and this may greatly impede infiltration.

Some small depressions (GILGAIS) form as a result of the swelling and shrinking of plastic clays. These are circular in outline and are useful water-capture systems where erosion has left them as hollows. Sand-filled they cease to function.

It is in the great tectonic depressions that salt lakes and dune seas (DRAAS) form; smaller depressions gather run-off and develop typical base materials of suspended silts or salts carried by the water and left on the pans when the water evaporates. A typical desert profile is given in **Figure 11.19**.

Soils in older deserts usually show some yellow or reddish colour from a complex of iron oxides, but areas may vary in composition from free sands to heavy, compacted, or cracking clays, which becomes notoriously sticky if wet (preventing all vehicle movement). Clays are most typical of flats and evaporation pans, and the softer clay-loams typical of dune swales and foothills.

SCALDS

A scald is the name given to a bare clay-pan or where a duplex soil (originally light sandy loams over a sharply-defined transition area with deep clay below) has lost its upper soil layer. Clays remaining are often *solonetic* (with a high content of sodium ions). As a result, the clays tend to "melt" when first wetted in rain, effectively sealing the surace of the clay base and preventing infiltration. The wet crust so formed on the surface is almost impermeable; the same effect is used to seal clays deliberately for use in leading run-off water to tanks. Scalds are not hollows, but have a flow into and out of the area (as opposed to claypans).

However, if a bank is graded up to 10–15 cm high, with the cut on the *lower* side, water will back up a considerable distance. Let this distance be one-third of the total area to be treated, allowing two-thirds of bare soil as run-off. Seed pre-sown on this surface will germinate, the low bank will eventually "melt" flat, and the next one-third can be treated as a successional strategy (**Figure 11.20**). Over 2–3 years a complete vegetative cover can be re-established. If banks are made too high or too solid, the plants will drown. Spiral earth-casting and ridges sown at their apex are also successfully used to seed claypans.

Revegetation of scalds is important, because in Australia at least, plague locusts lay their eggs and hatch most successfully in the narrow shaded edges of the scalds. Most scalds are produced by over-grazing, so that the desert grazier inflicts plague on whole regions.

CLAYPANS

Unlike scalds, claypans rarely overflow, but receive silty waters from clay soils, and after they pool for awhile, clay settles out and water evaporates. In the wet phase, tall canegrass (*Eragrostis australasica*) can grow, duck and waterfowl nest, and as the swamps dry out, marsupials and rodents take refuge. These swamp areas were frequently burnt by Aborigines in autumn, or as the canegrass dried out, but regenerated in wet periods.

Non-saline eroded claypans have also been revegetated by pitting, by building flood retention banks, and by chequerboard ridging. A low bank of 0.5–1 m is sufficient to support adapted trees in saltpan areas. The trees then assist desalination. Ploughed or ripped clay allows faster water infiltration, and vegetation keeps the initial crevices open if dry-leaf mulch species are avoided, and herbaceous or needle-leaf groups substituted.

SALTPANS AND SALT LAKES

These can hold many metres of water in floods. When this water evaporates, great depths of salt may accumulate, sometimes with a thin clay top. Vegetation of salt-tolerant plants occurs only on the margins.

Salt enters the freshwater zone in sandy deserts and atolls from these sources:

- Salt is washed *down* by infiltration of water through saline surface sands.
- Salt diffuses *up* from deep, heavily-salted waters (usually saltier than the sea).
- Salt *advects* in rains from the sea or saltpans after rain. This effect is most pronounced if freshwater has been overdrawn from the ground.
- Salt is drawn *up and in* by forceful pumping locally, and then pollutes surface soils.

GILGAIS

Gilgais are "puff and hollow" areas formed by patches of clay 3–5 m across, which expand into 6–20 cm deep hollows on a "swell-shrink" regime. The hollows occur in solonetic clay soils which shed their water into the hollows. The hollows can link up in chains or patterns,

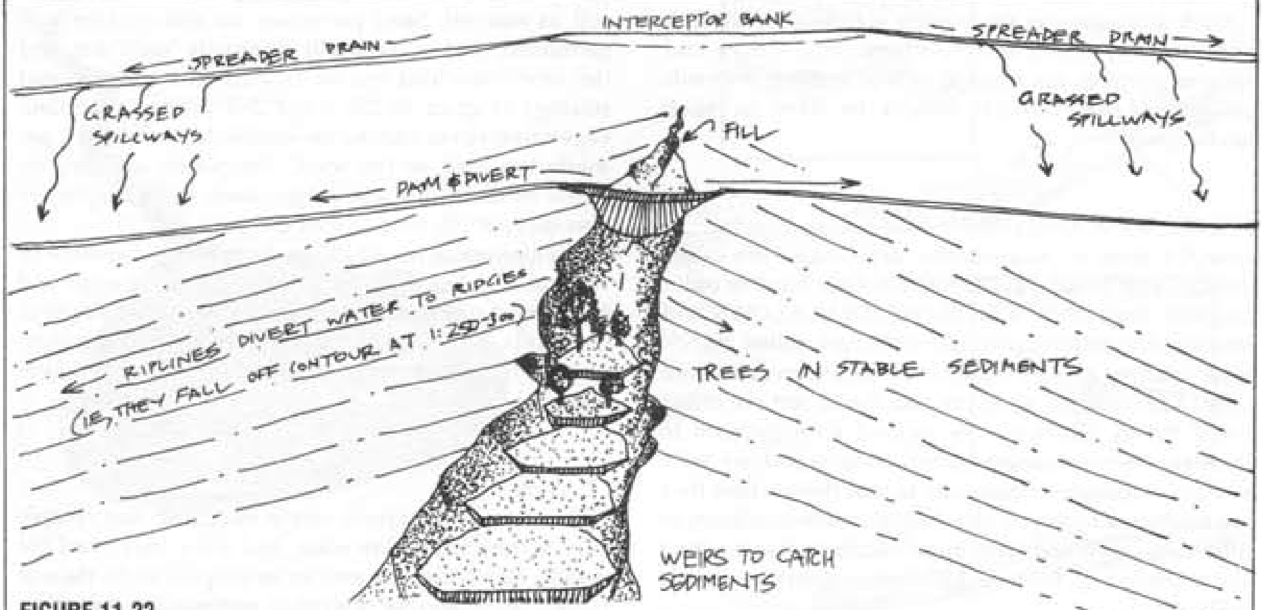


FIGURE 11.22
RIPLINES DIVERT WATER FROM GULLY EROSION.
Riplines from gully lip at 1:200 or less to ridges divert sheet flow away from gullies, as do swales; trees stabilise gully sides (see also FIGURE 11.21).

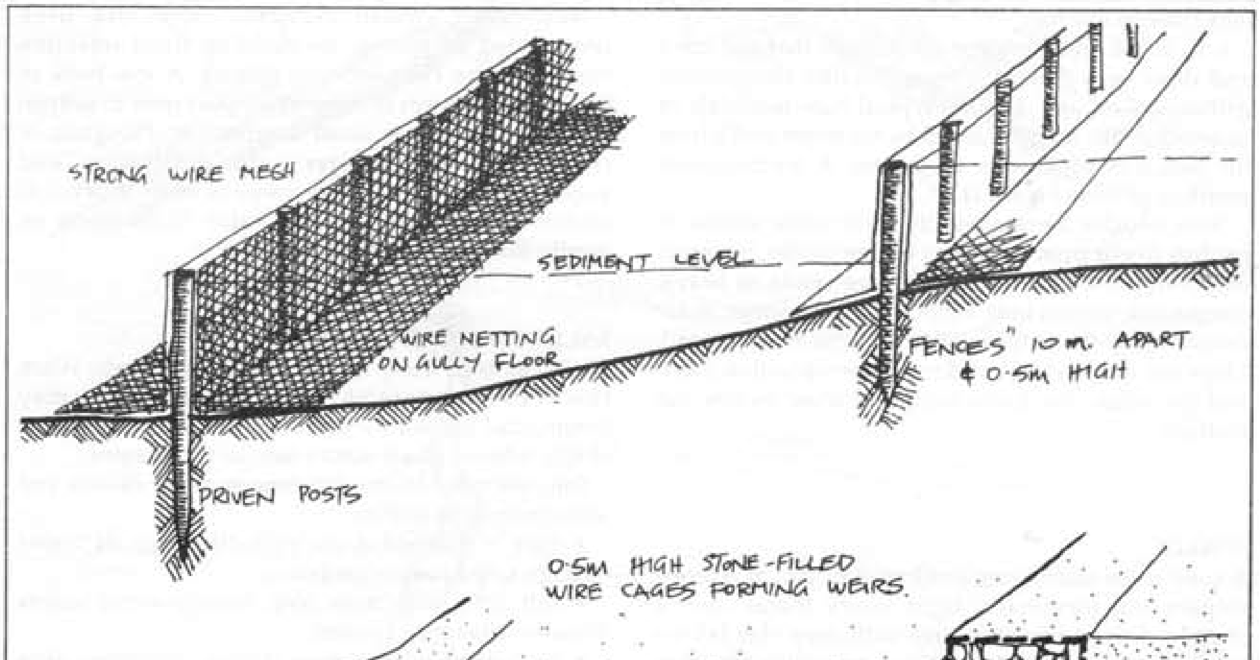


FIGURE 11.23
A SERIES OF WEIRS AND GABIONS.
Gully erosion fences or weirs need splash aprons, and need to be keyed into gully sides; low fences (0.5–1.0 m) are more likely to survive floods.

and the whole area is rich in plant species.

Where the area is overgrazed, the gilgais become sand-filled, the solonetic clays wash away, and a series of sandy mounds evolve. The area loses most of its plants and becomes unstable.

FLOOD-OUTS, GULLIES, BADLANDS

Also called flat-outs, or run-ons, these are the ever-widening flattish floors of valleys as they leave the hills. These "streams" are only 2-8 cm deep and 20 m or more wide, braided, and stable. Water absorbs over a wide area of such plains. Overgrazed, the streams commonly first erode some deeper channels, then become steep gullies. At this stage, diversion of water from gully heads, water spreading from large canals, and gully planting must be applied. Small gullies can be filled, and larger gullies planted behind stone walls or gabion barricades once the feed water has been diverted or spread (**Figure 11.21**).

Controlling gullies is essentially a matter of:

- Relieving the causes, usually those of overuse and lack of water control; and
- Preventing further cut-back of the gullies.

Fragile soils, loose shaley ground, and recent sediments exposed to sudden overland flows may gully in a few downpours. In deserts, this most frequently occurs where foothill flood plains are overgrazed, where rabbits tunnel into loose subsoils, where vehicles or cattle create downhill tracks, or where badly built roads direct sheet flow to culverts that concentrate flow. Such areas need fencing out, light or no stocking of animals, pest control, and above all, spreader banks for the water.

In the valleys above the gullies, stream flow can be diverted to flood spreader channels, and a series of rip-lines drawn downhill from the gully bank towards the ridges (sloping at 1:1000 or so). **Figure 11.22**. Small gullies can be bulldozed full, or interceptor drains made across them to cut off flow. Large gullies can also be filled or dammed if soils are suitable, but extensive gullied badlands are too expensive to treat in this way, and we may need to fall back to creating small silt dams in the valley floors themselves.

As with many dryland techniques, gully retention banks need to be small, frequent, and well-made to effectively spread flow and create absorbent flats where water trapped in silts create beneficial growing media. In many areas, once gullying has developed, there is no alternative to allowing water to flow in the gully systems and to create fields there.

A series of weirs 0.5 m high traps sediment so that tree establishment can stabilise the run-off. Weirs can be made from a series of well-braced wire-mesh fences or low stone bunds across gully floors, or stone-filled wire baskets (GABIONS) placed to spread the flow of floodwater. **Figure 11.23**.

If the weirs are higher than 0.5 m it is necessary to provide a splash apron at the foot of the weir where plunge pools form. However, if interceptor banks can be made above the gully-head, and water diverted, then the lower volume of flow permits weirs of 1.0-1.5 m high without scour damage.

All weirs are started at the gully outlet, and built in sequence upstream. Where no local supply of boulder is available, the lower height of weirs are built of wire mesh only. Where there are plentiful stones, stone seepage weirs are very satisfactory and form roads across the gullies.

Weirs must always extend up the gully sides, well above any flood level. Stone weirs are more easily maintained and restored than wire fences, and more permanent. All weirs need Vetiver grass or some such tough plant barrier to hold erosion.

At projects such as that at Assomada (Cape Verde) in the Sahel (*International Agricultural Development* Jan/Feb 1985), terrace-building and check dams built of stone-filled wire mesh gabions in the stream beds have effectively checked and stabilised soil erosion. Both help to absorb run-off water. A change from sugar cane cropping to tree and vegetable culture also assists soil conservation and aids local nutrition in this area of high unemployment. Some 2000 ha have been reclaimed in two target valleys.

Pigeon pea *(Cajanus cajan)* has supplied food and ground cover, and cooperatives have formed to grow and market food, with credit provided for crop production. Wells and galleries dug to tap groundwater

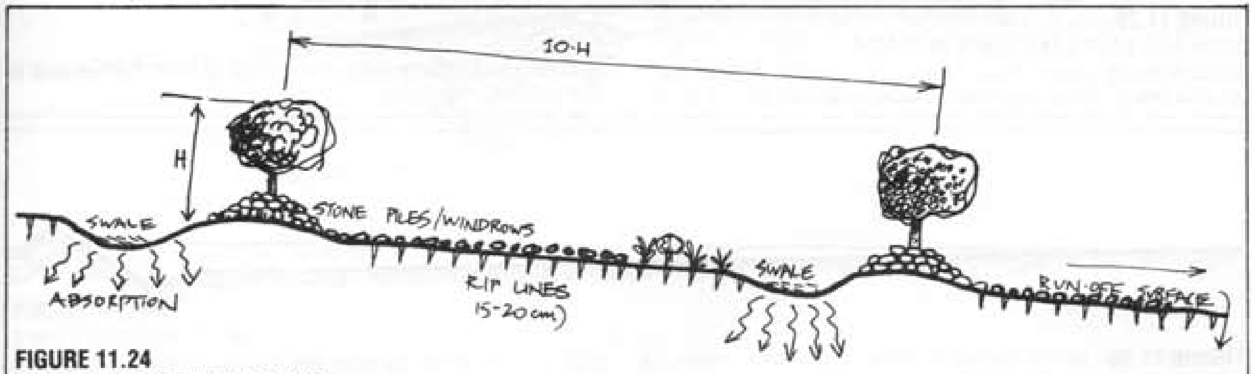


FIGURE 11.24
GIBBER DESERT IN WINDROWS.
Stony desert windrows, side-cast downhill are excellent tree sites; associated swale infiltrates runoff on contour. Cautious trials should precede broadscale windrows as trees are needed to prevent dust.

have served to establish tree and vegetable crops. The silt brought down by erosion has built terraces 6–8 m deep and about 200 m wide across eroded valleys, and copious spillways let floods flow over. A change from goats and sheep to rabbits and pigs have helped replace animals that overgraze the hills to those suported by domestic wastes. In all, the project has integrated several important biosocial strategies to make modest improvements to a degraded area:

• Government aid is available as revolving loans, to plant new crops and to buy in alternative livestock (replacing erosive species).

Community involvement is assured by the employment and education of unemployed people towards projects that relieve their poverty (meaningful local work).

• Education is integrated with development.

• Export crop is being replaced with local nutritional food crop and tree crop.

• Pioneer legumes have helped improve soil and halt erosion, while providing forage and food locally.

STONY (GIBBER) DESERT

Vast areas of desert may develop a stone layer over fairly well-structured soils, the stones being once part of a soil matrix, but now revealed after centuries of wind erosion. Old stony deserts have wind-faceted stones, whose facets reveal the direction and intensity of local sand-storms, or the saltation of sand grains in wind.

Wherever a road grader passes across this country, a windrow of stones results; large sturdy side-rakes are now developed which will also windrow stones in fields or on gibber. It is these windrows that present a great opportunity to soak in run-off and to start tree lines across slope every 10–20 m. The bare area between windrows not only gives greater run-off, but provides a seed bed for smaller shrubs, legumes, and forbs. Insects, reptiles, and birds leave manures and their remains in the windrows of stones. Water is impeded and largely absorbed below the stone piles, and dew forms in aerated heaps. If practical, ripping the pavement below or between windrows helps root penetration, and a touch of fertiliser greatly aids growth. Swales can be made just upslope of windrows (**Figure 11.24**).

Some natural stone windrows evolve below cliff shorelines on receding lakes. Below the stones the soil is cool, moist, and obviously well-structured due to insect occupancy. Many tree species appreciate these conditions.

REG (gibber desert) is stabilised only by the layer of stones. (Active dunes can also be stabilised by laying pebble beds over them.) Thus, if there is any disturbance of the stone layer, erosion can recommence, so that windrowing stones for annual cropping is certain to *increase* erosion. However, windrowing in stages to plant trees at 10–30 m intervals (in stages, because we need to assess the possibility that we would be able to grow trees there) will reduce erosion and also trap dust from outside the area, or bring sand to rest. Like a great many desert techniques, a limited trial is needed before broadscale windrow systems evolve. It is thought that the Nabateans made windrows on steep slopes in order to increase run-off, and to lead water by hill-base channels to fields, but good absorption does occur in

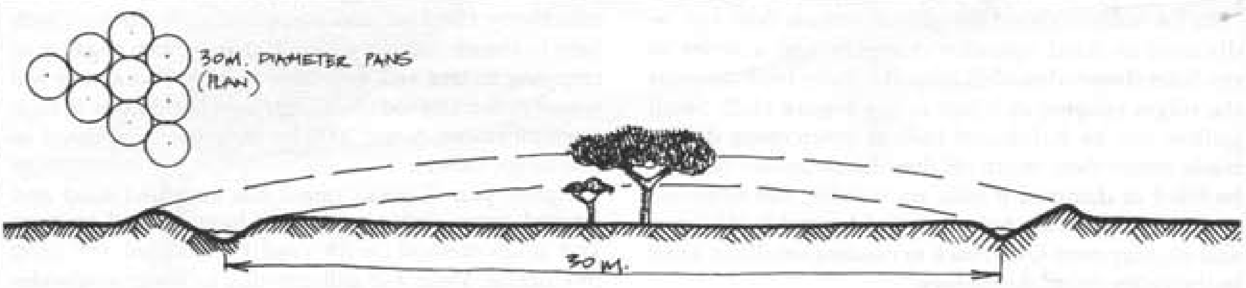


FIGURE 11.25
DITCH AND BANK LANDSCAPE IN PLAINS.
Circular side-cast pans of 30 m or less diameter prevent all runoff and will grow forage species in perimeter swales; ideally, smaller (20 m or less) pans may become partly over-shaded by trees. Pelleted seed in ditches helps revegetation.

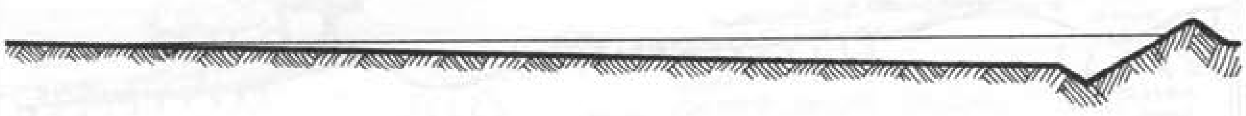


FIGURE 11.26
YEOMANS' SHALLOW SWALES.
Very low (1–1.5 m) banks on flat deserts hold back runoff water for up to 6 km; bled off to fields, and infiltrated, this water is useful for opportunistic crop (sunflower, millet).

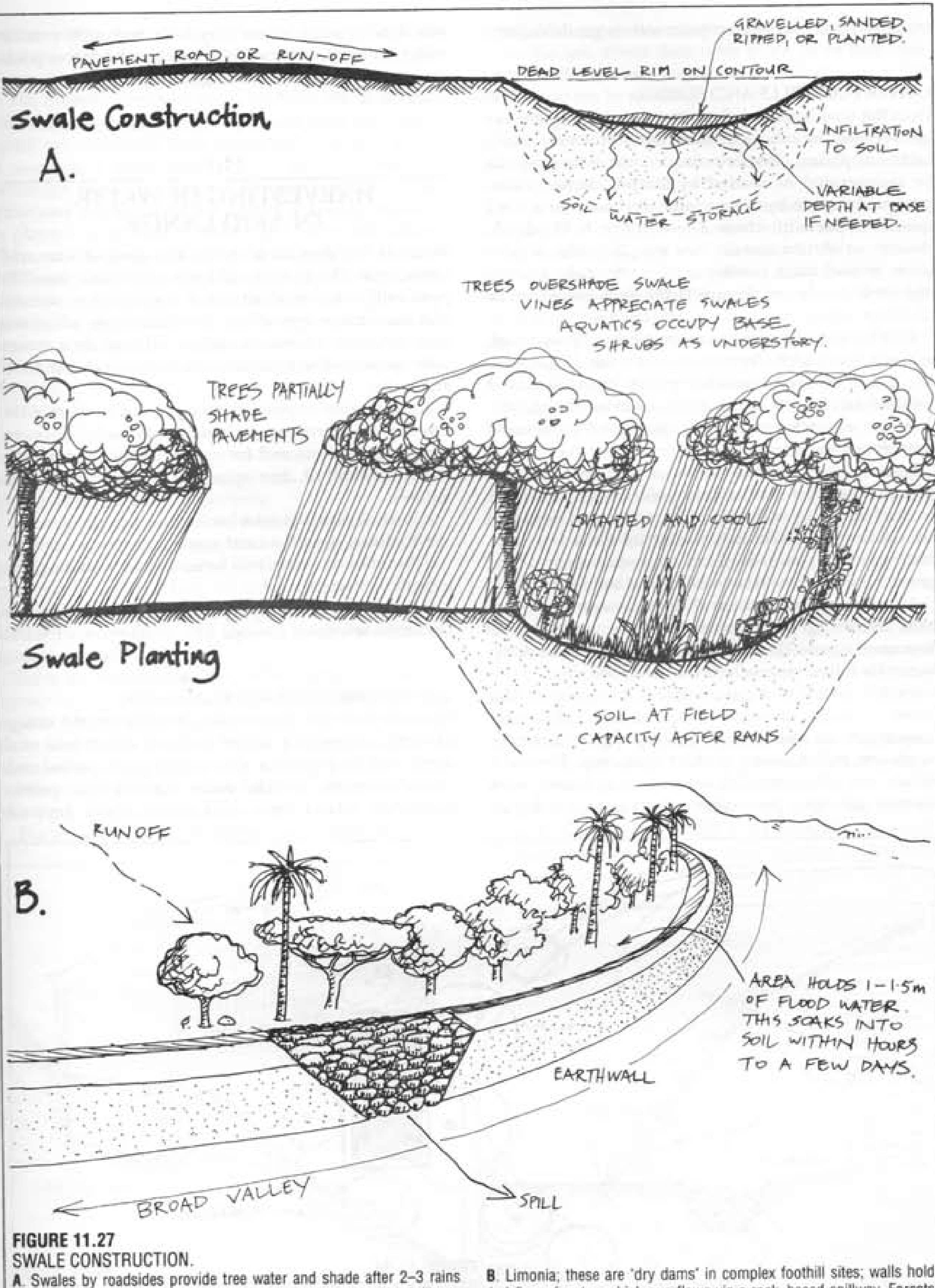


FIGURE 11.27
SWALE CONSTRUCTION.

A. Swales by roadsides provide tree water and shade after 2–3 rains infiltrate; this can be used to cool urban streets. Many swales infiltrate water in from 2–48 hours and provide ample tree irrigation after early establishment.

B. Limonia; these are 'dry dams' in complex foothill sites; walls hold 1–1.5 m of water, which overflows via a rock-based spillway. Forests or citrus groves, olives, palms, can establish in the base of limonia.

windrows over clay or clay–loam soils in gentle slopes.

LOWER FOOTHILLS AND PLAINS
Even flat land has some slope (not detectable by the eye but revealed by rains and sheet flows of water). These extensive plains, often browsed to near extinction, can be regenerated or seeded by simple circle–swales, preferably made by tractor and tilt blade, or a road grader. Especially where a few saltbush, bluebush, *Acacias*, or shrubs remain, one simply drives a great circle around them, casting earth *out* to make a "ditch and bank" landscape (**Figure 11.25**). Such circles can be 30–100 m across.

This too has succeeded in re–establishing poor range, as seeds, leaf mulch, dry manure and water all gather in the ditch. Where no mother plants exist, seed and fertiliser can first be broadcast to await wind and rain. A series of such conjoined circles totally prevents run–off and traps seed and dust.

Equally well, graded contours will back up and absorb water for a relatively great distance. I have worked on plains with falls of 10 m/km, and here a 30 cm contour wall will hold water up for a few kilometres in heavy rain. Seed can be sown as soon as the ground is firm, or pelleted seed spread beforehand.

A scale larger than these shallow swales is a 1–2 m bank thrown up by repeated side–casts, used by P. A. Yeomans in semi–desert (**Figure 11.26**). These back up water for miles, especially if the banks are sited to run from hill to hill in a pass between low ranges. The water can be left to soak in, or spilled under slide–gate control into yet smaller walled fields to grow a crop of sunflower, millet, beans, or short–term crop. Trees and shrubs will often establish well on these bunds. Such systems suit fairly permeable soils, but can develop as salt flats in areas where clay soils and salty surface water is used. Crops can be sown as such lakes or pools dry up, in sequences following the receding waters.

11.6
HARVESTING OF WATER IN ARID LANDS

Water is the dominant theme for designers in arid landscapes. The quantity of fresh water (less than 700 ppm salt) is the final arbiter of successful settlement and sustainable agriculture. To obtain fresh water, we must intercept it before it washes salt from soils, mixes with deeper saline groundwaters, or runs off roof areas and rocks.

To open this section, I have chosen to start with TANKS and proceed to broadscale techniques on specific landforms and for specific slopes. Regarding water catchment, our aims can be summarised as follows:

- To store *fresh* water for cooking and drinking;
- To divert sheet flow and waste water to gardens;
- To infiltrate water into soils, and to produce plant growth on that site; and
- To give rainwater run–off time to soak into the landscape where we live.

THE CONSERVATION OF RAINWATER
Here, we have two basic strategies to apply: the fitting of tanks, cisterns, or sealed wells to take house roof water, and the provision of very large public sealed and roofed resevoirs to hold water run–off from public buildings, paved areas, and roads. Many dryland

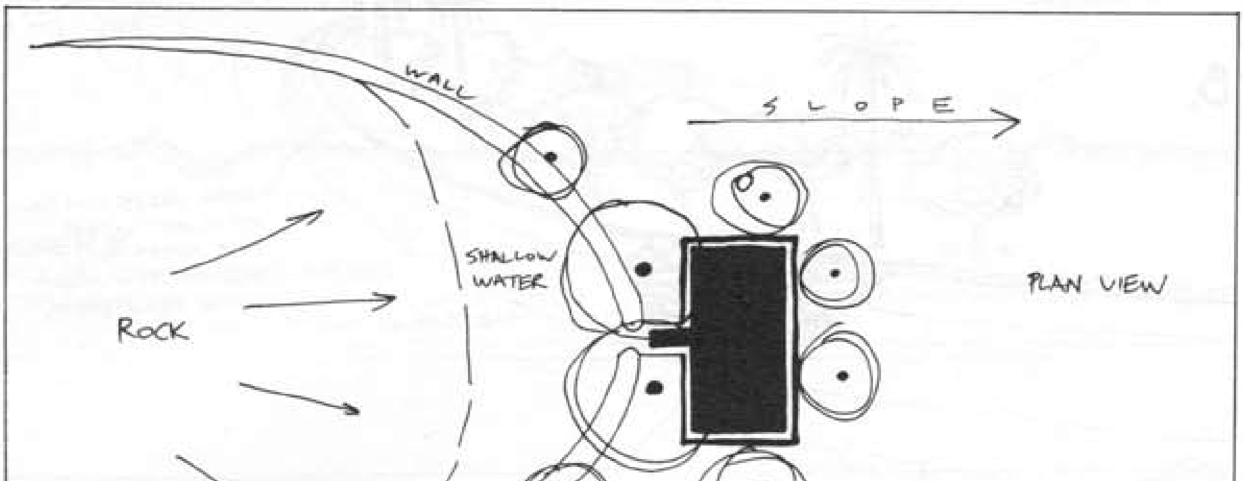


FIGURE 11.28
BARE ROCK SLAB WITH GUTTER TO STORAGE.
A roofed cistern stores rock slab water for houses or wildlife; some towns create an "ironclad" area by roofing or concreting on hillslopes.

settlements in Australia have public cisterns. These are used for domestic or agricultural water, depending on the quality of run-off.

The cheapest water storages for trees are in permeable earth swales (of any shape) alongside the roads, which are essentially large compacted collection areas. A swale is a dead-level hollow built on contour (although the base need not be level) which create temporary pools. Swales are ripped, gravelled, sanded, or planted at the base to assist rapid water infiltration. They must be large enough to take all tank or storage overflow, pavement run-off, and additional harvested and diverted overland water flow from the environs outside the settlement itself. In short, they may need a capacity of 200% of village run-off which then infiltrates locally as soil water storage to 3–5 m down in the earth.

Village Homes (Davis, CA, USA) is fully swaled, and grows its trees on water so harvested, planted in or beside the swales themselves. After a few rains, ample soil water is available for tree growth. In Mexico swales are used along main road sections.

Apart from the greatly reduced cost of eliminating stormwater drains, gutters, and kerbing, swales will grow the very trees needed to shade the pavements, courtyards, and parking or market areas that they serve. Swales also provide dirt spoil to raise road-beds, sand for construction, and topsoil, loam, and clay for gardens.

There are two approaches to the problem of water conservation in homes and buildings; the first (a regular feature of life in arid-area towns) is to allow a strict household ration of water per person. This is achieved by using the simple strategy of fitting float valves to all home roof tanks (of fixed dimension), and pumping them full only once a week.

The second is to strictly meter use—a more generally acceptable approach—and put a sliding increase scale on excess use. Waste then costs much more than conservation. Meanwhile, inside and outside the house, the most water can be saved by:

- Using the least possible in gardens, especially by planting shrubberies instead of lawns, and using sub-surface trickle irrigation, mulch, and shade. This can save about 50% total water use.
- Saving water by less use, especially on toilet-flushing. If hand-basin and raised-floor shower water is fed to a low-head, low-flush cistern (with overflow by-pass), then 40% of the remaining 50% of water use is saved. Further, bathwater diverted to a pre-soak trough for clothes, and laundry water to the garden makes good use of this waste water. Water-saving shower heads and timer taps stop us dreaming in the shower and save 14–20% of water so used.

Whenever kitchen sink water is used, it too can be diverted to the garden and used productively. Every family roof should catch its own drinking water in tanks of from 20,000–50,000 l (5,000–12,000 gallons), depending on family size and regularity of general supply.

In a few sensible towns in Australia, *all* roof areas are run by public pipeways to large storage tanks, and all road run-off to resevoirs to be used on public gardens. Other settlements run all road water to swales where trees and fruit crop are growing .

Much simpler but still quite hygienic systems use "rope and pulley" showers, basins for hands and laundry (often under a lean-to) and earth-closet toilets. I have spent most of my life using such systems in bush camps and in pre-war houses. They work well and save a great deal of water, usually a fraction of that caught on roof areas and stored in house tanks.

Only 1 cm of rain produces 1,000 l for a roof of 100 square metres, or 100,000 l/ha of sealed run-off. Domestic tanks are built at about 20,000 l (to 100,000 l for small settlements). Any multiple of these tanks can

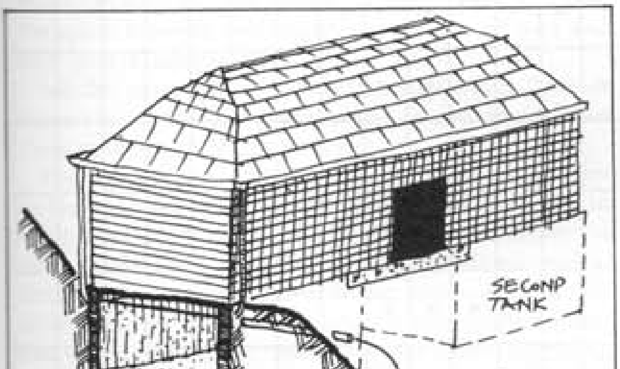


FIGURE 11.29
LARGE TANKS FORMING FOUNDATIONS.
Uphill barns will fill large cellar storage tanks from roof catchment for gravity flow to house and gardens.

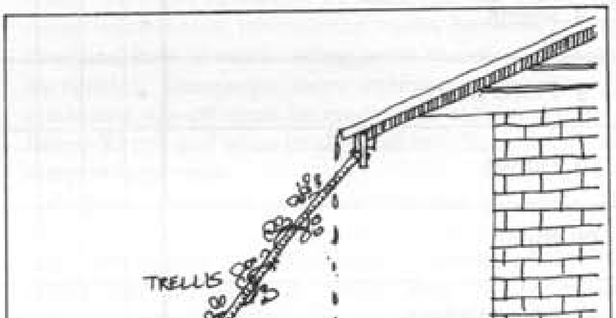


FIGURE 11.30
SWALES FOR ROOF DRIP.
Small stone-filled domestic swales provide a shaded soil-water source for vine trellis.

TABLE 11.2

A GENERAL SUMMARY OF WATER STRATEGIES FOR DESERTS; APPROPRIATE USAGES AND SITES.

SITE	1 Fields (soakages)	2 Open dams, scour holes	3 Check dams	4 Sand–filled dams	5 Swales	6 Spreader drains	7 Catchment basins	8 Chequerboard ridges &bunds	9 Low contour ridges	10 Pits and burrows	11 Net and pan	12 Leach fields	13 Moisture barriers	14 Run–off (paved areas)	15 Boomerang bunds	16 Log and rock check	17 By–pass channels	18 Tanks and cisterns
1 High hard plateau surface			•													•		•
2 Rills in stony country, slab rock			•	•												•		•
3 Shaded rocky valleys		•																
4 Upper valley systems	•				•	•									•			
5 Wadis and wider valleys, dongas	•			•				•									•	
6 Flood–outs	•					•											•	
7 Low foothill slpes (4–8°)	•	•			•	•	•		•		•							
8 Plains	•				•			•	•									
9 Flood plains	•						•	•										
10 Dunes										•								
11 Pans								•	•	•								
12 Large valleys	•	•		•														
13 Steep slopes (8–15°)									•	•					•			
14 In towns and settlements					•							•	•	•			•	•

be built of concrete, using a central vertical pivot and sliding form in which to pour the concrete. It is easy enough to scale up or down from these figures when estimating tank or swale capacity needed for dwellings.

Even in very low rainfalls of 10 cm or so, large rock or roof run-off surface will supply all the drinking water that we have tanks to store it in. Because of the costs of building cisterns, we can seldom afford to store all the rain it is possible to catch.

Roads are commonly sealed and otherwise compacted by traffic, and in desert downpours collect large expanses of water. In other areas, we can seal hill slopes above villages with concrete, wax, bitumen, or plastic, and use the area as a "roof". But the cheapest roof is to locate near a bare rock slab in granite, or a natural sealed cap on hills, around which we run a gutter (rock-cut or cemented) to storage cisterns or tanks.

Tanks (versus dams) can stand on or above the soil surface, and are fully sealed and usually roofed. Large tanks have a roof which is itself a catchment to the tank. Sometimes a tank is excavated and sealed with a tough plastic or rubber membrane. Sites are usually chosen above houses or settlements, and an accessory windmill in foothill settlements (or a solar-powered pump) is used to lift clean groundwater from wells to tanks in any period of higher demand. On very flat plains, the tanks are raised on a stand, and the windmill lifts to the tank for house and stock water—a very reliable and widely-used system even in towns. Some figures (as an aid to storage planning) for arid areas is shown in **Table 11.2**.

Large garages, factories, recreation halls, and shops provide ample roof area for catchment in most communities, and are so used in arid areas. The tanks themselves can be earth-sheltered, partly or fully buried, covered with vines, or they can stand in shaded courtyards. Sited uphill from houses, large ground tanks can form the foundations of barns or garages, and the space between such tanks a cool store for root and fruit crop (**Figure 11.29**).

All the more wonder, therefore, that (apart from in Australia) tanks are a rare event in settlement, and clean rainwater is let run to waste.

There is seldom enough storage for *all* our roof water in tanks, so we can then run the overflow to swales in the garden. Such swales can be simple channels, or (in deep sands) long plastic-lined and sand-filled swales, from which we can pump water, and on or beside which we can grow plants. This surplus garden water can be augmented by shower water from the house. Neat swales for roof drip are made from rock-shingle-filled hollows or channels with vertical concrete edges, but unsealed below to allow infiltration (**Figure 11.30**).

There are some myths surrounding the storage of water in tanks:

1. It is stagnant water (untrue; it tastes fresh for years and remains clear and clean).

2. It breeds mosquitos (not true of *covered* tanks; mosquitos can be totally excluded. In open tanks, mosquito-eating fish can be stocked).

3. It contains dust, etc. from the roof (true, but this settles as a biological sediment and keeps the water clear).

Generations of healthy Australians have been reared on tankwater (myself included), and have escaped cholera, bladder cancer (from asbestos pipes), heart attacks from acid water, and the 46+ additives now used in reticulated water. Get a tank and survive! Tanks can be brick-lined, domed, and rendered in sandy soils, built of "stack sack" (plastic tubes of 1:9 cement:sand, pricked and soaked in water) in plastic-lined holes, built of cement plaster on a wire-netting base, excavated in rock, or poured of concrete in mobile steel forms on site or at the factory. They are also made of (or lined with) galvanised steel, fibreglass, plastic, or plastic resins.

It is beneficial to place limestone, dolomite, or marble gravel (or mollusc shells) in a bag in every tank to offset acidity, to fix metallic salts, and to "harden" the water, as it is healthier to drink alkaline or neutral water (less heart attacks, less metals in the diet). The fitting of tanks in arid areas should be *integral to every building*. At the least, every home can drink its own tank water; and at most a large house roof will grow a home garden and orchard on wastewater and overflow.

WATER HARVESTING ON OPEN SITES FOR TANKS OR CISTERNS

Wherever good clays are found, we can make earth tanks in the ground. The essentials are that:

- Tanks should be deep and narrow;
- They should intercept a run-off area; and
- They should ideally be roofed to prevent evaporation.

By instituting a system of cisterns, tanks, and swales, any desert settlement (wherever average rainfall exceeds 30 cm) can create for itself a reserve of soil and roof water that is, in effect, an oasis. The proportion of water supplied to swales by local run-off and from more widespread interceptor banks harvesting the overland flow of surrounding areas therefore changes as rainfall decreases; more extensive harvests of landscape run-off must be made once rainfall declines below 30 cm, and must be directed to village swales to support large trees.

Both for domestic and livestock use, a variety of deliberately sealed or compacted run-off surfaces have been constructed in Australia and elsewhere. Some of these are at ground level, and range from bitumen-sealed and fenced areas to roaded catchment of 300 m long by 10 m wide rounded and graded surfaces; side slopes are at a ratio of 1:20, drains at 1:100–1:200. The earth can be stabilised by gums, a light cement mix, or simply well-compacted clay soils. **Figure 11.31**.

Other approaches are the sheet metal roofing areas of up to 600 square metres, at ground level, feeding to 100,000 l tanks. Slopes covered with roof metal can be steeper than those of earth. It can, of course, be

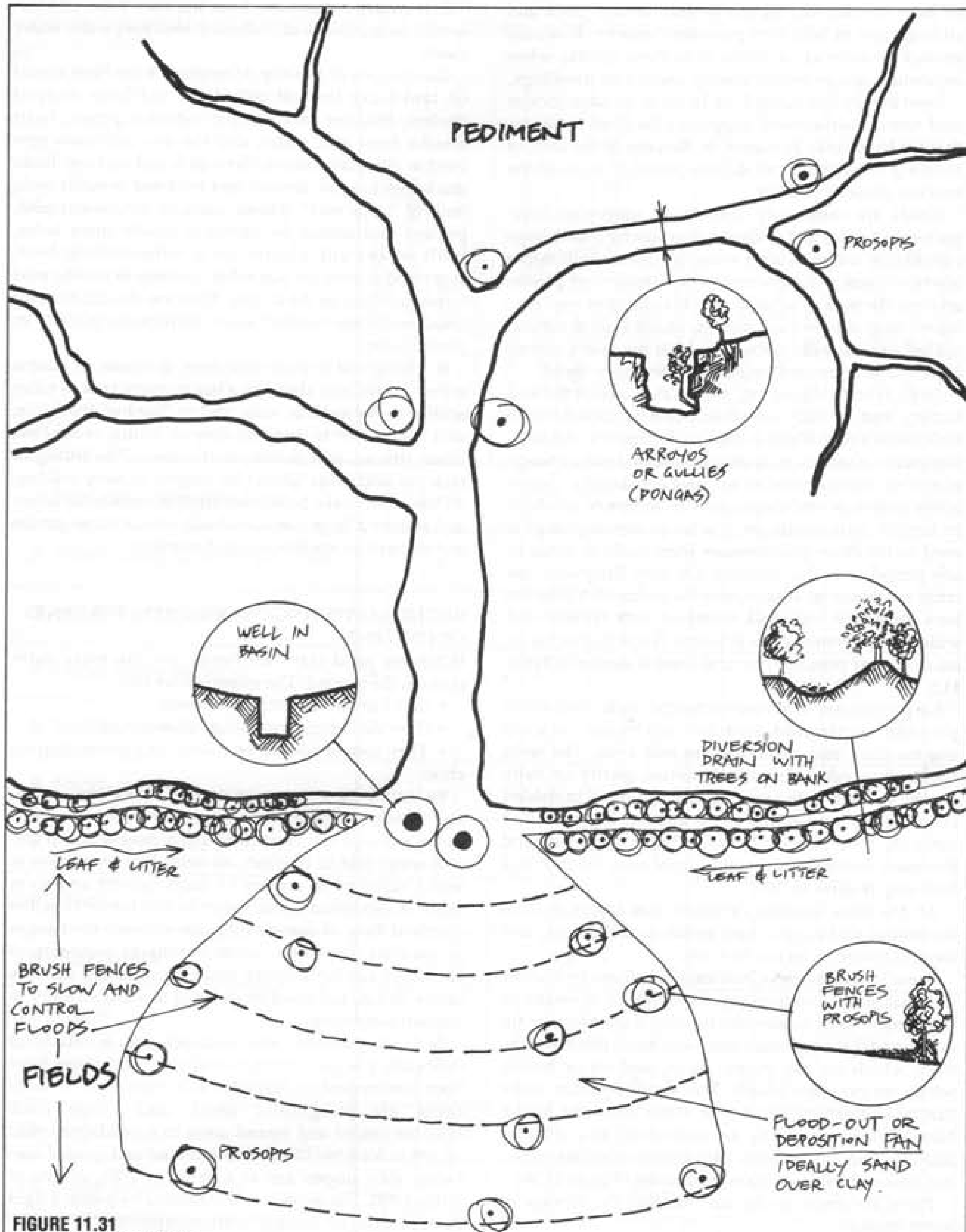


FIGURE 11.31
RUN–OFF AGRICULTURE
in "flood outs" or silt pans in basins; a schematic of Papago Indian (O'odham) brush–walled fields. If arroyos spread sand over clays, the fields are excellent growing situations. Strategies apply to Botswana, Southern Africa, Australian deserts.

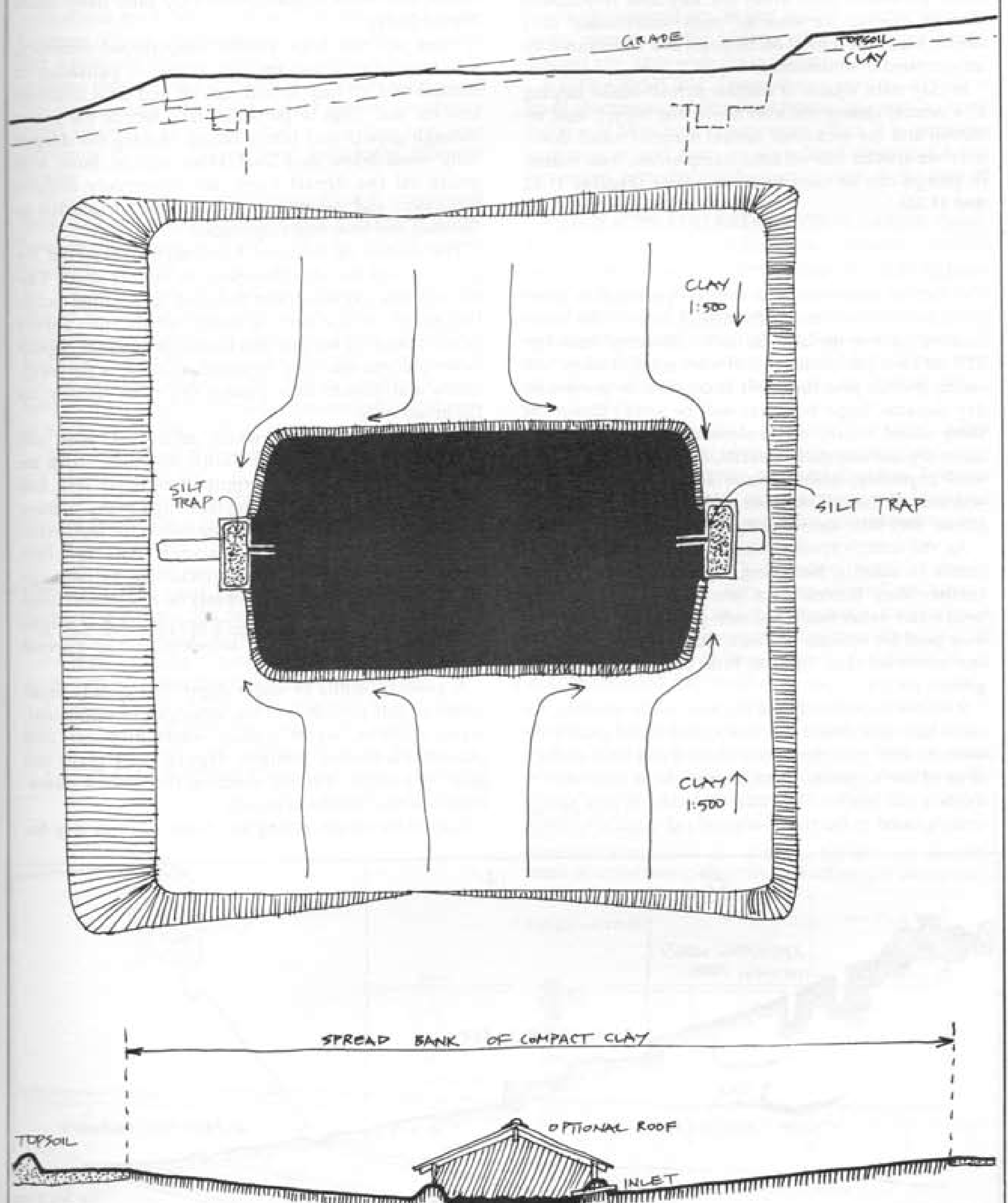


FIGURE 11.32
CLAY CATCHMENT SLOPING TO CISTERN. (Elevation).
Clay soils can be excavated to run water to a central roofed cistern for stock or garden use. Screens are necessary at entries to prevent small animals drowning.

advantageous to actually use galvanized sheet iron to cover extensive roof areas for hay and implement storage, or even for lease as "mini-warehouses" near towns. Many such roofs on factories and warehouses lie unharvested in settlements.

In clay soils, square or circular spread-banks sloping to a central cistern are also made, the topsoil first removed and the excavated central material rolled down to create a water run-off area. Ramp access, base drains, or pumps can be used to access water (**Figures 11.32 and 11.33**).

WATER SPREADING

The fate of rainwater in a thinly-vegetated or overgrazed desert area is usually that of most of the water running off over the land. So little is absorbed (less than 12% in bare hill country) that even modest rains will create sudden and turbulent flood flow in previously dry streams, large boulders will be swept down the steep-sided wadis, and enormous quantities of silt, sand, dry leaf and stick material, dry manures, seed and seed capsules, desert snails and other debris are washed off the hill surfaces and carried out onto the plains. Very little soil water is retained.

As the waters spread out over the plains, they increase in salinity, becoming rapidly more saline the further they travel. In a few days or weeks, the headwater rains reach the salt-pans, and there they may pool for months or years, until they evaporate to salt-encrusted flats. In total, little but ephemeral plant growth results.

If we are to creatively use this rare water resource, we must halt and divert the flows, and make places for water to soak in to the soils while it is still fresh enough to be of use to plants. Once fresh water is infiltrated, it forms a soil reserve or aquifer that travels very slowly underground to the river beds and salt pans, effectively de-salting the shallow water reserves, even though below this fresh aquifer flows very salty deep leads **Figure 11.34**).

Trees and tree lines, swales, deep-ripped contours, silt dams, dams, and lines of stones or palisades of natural rock all help to halt run-off and let it infiltrate into the soil. Trees in particular help recycle the water through growth and transpiration, keeping the deeper salty water below root level. When we cut, burn, and graze off the desert trees, we effectively reduce infiltration and the deep leads rise to the surface due to flooding and bare-soil evaporation.

The forests of Ethiopia have been devastated by grazing and the development of export crop. The rainfall has likewise been reduced, and salted lands increased. If we put as much effort into forest rehabilitation as we put into lawns, or as much capital as we put into war, then we could rehabilitate the earth. China and Taiwan have proved this to be feasible on the broad scale.

As we cut forests everywhere, aridity and fires, salt and sterility will increase. South Australia (with an impoverished 3% of her original tree cover left) has banned all new forest clearing (although many farmers cleared as much as they could just before the legislation was enacted). This is not enough. Any sensible government would allow agriculture as perhaps 20–30% of a total land area; we rely on forests and lakes to support even this area of crop and grazing. It is time for farmers to also become foresters, and so prevent future disasters.

A general profile of water depth and quality from intake to salt pan decides the strategies of settlement, water systems, water quality, water disposal, and placements (hence, design). **Figure 11.34** gives the general pattern. On hill country, the second determinant is frost level and aspect.

Rain in the desert, falling as 2.5 cm or so per day for

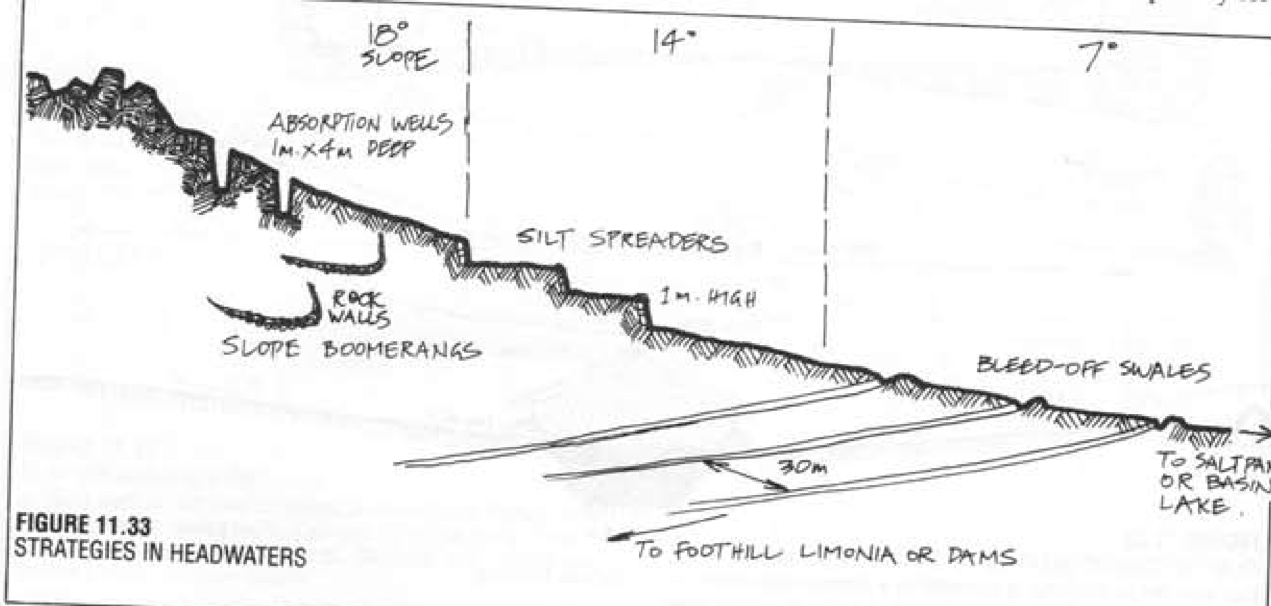


FIGURE 11.33
STRATEGIES IN HEADWATERS

2-3 days (as it does), is likely to produce severe local flooding, and this too must be kept well in mind when settlements are located or built. This flash-flood factor becomes critical when settlements are built in wadis, on the upstream side of restricted gaps in hills, or in hollows near dry watercourses. If we are to store or use the intense, sudden and infrequent falls in deserts, we need oversize channels, drains, infiltra-tion, and diversion systems to cope with such high- intensity storms.

In Australia, 88% of rainfall runs off or is evapor-ated from land and water surfaces. Other hot deserts would have similar losses, with only 12% of rainfall available to plants. Normal estimates are of 12% water run-off for forested areas, 20% for non-forested areas with sandy or friable soils, and up to 80% for the rare concreted, compacted, or clay-sealed bare sites. These few figures enable us to make educated guesses as to the volume of run-off water, and hence the capacity needed in channels or flood by-passes in any arid area, or to estimate flood levels in valleys.

Some precipitation intensity figures (mm/24 hours) are listed in **Table 11.3.**

Given such daily rainfall intensities, what are the typical proportions (percentages) of run-off we can expect from various substrates? It is the percentage of run-off that will decide the proportion of storages needed in arid areas (as soil or swale storage, pits, dams, or cisterns). We presume a rainy period at 10 mm/day. See **Table 11.4** (the data refers to arid lands).

As well as surface conditions, other factors affect water run-off. Some important determinants are:

- CATCHMENT SIZE small catchments discharge a greater peak flood flow than large catchments. Foothill areas will peak to floods more rapidly than plains.
- STREAM GRADIENT. Steep streams discharge more rapidly than downstream areas of gentle gradient. This is related to the factor above, as the smaller headwater streams are, in fact, usually steeper than the larger streams in the plains, which are often sand-clogged and have wide flood plains.
- SIZE OF STORM. Large storms may totally wet a small catchment, causing local floods, whereas the same storm will have little downstream effect. It is common, in deserts or arid areas, to see a flood disappear a few kilometres from the headwaters ex-cept in the case of very widespread rains.
- STORAGES AND RETARDATION BASINS. Dams, retention or interception banks, swales, natural swamps, and created swamps all reduce or delay flood peak. Local soil absorption is much more efficient in small streams of high density, but large catchments have greater dampening capacity for floods, providing such retardation areas are preserved for such purposes as flood control (many of these areas are drained, filled, or built upon)
- CATCHMENT FORM. The normal dendritic (tree-like) drainage patterns of rivers, where branches join at small angles, are subject to faster flooding (greater streamlining) than fold-mountain or fault-area grid catchments with their abrupt turns, constricted valleys, and relatively long runs of middle-order streams.
- DRAINAGE DENSITY (the actual length of stream per square kilometre). Very dense streamlines remove water very efficiently, and create higher and faster flood peaks. Sheet flow across the flat inter-fluves or off slopes in low-density areas retards flood-waters, as does the braided and broad streams of flat desert areas.
- VEGETATION. Run-off increases as vegetation is cleared. The less crown interception, humus storage, and ground interference encountered by rain, the more water runs off. If tussock grass replaces shrubs on dry

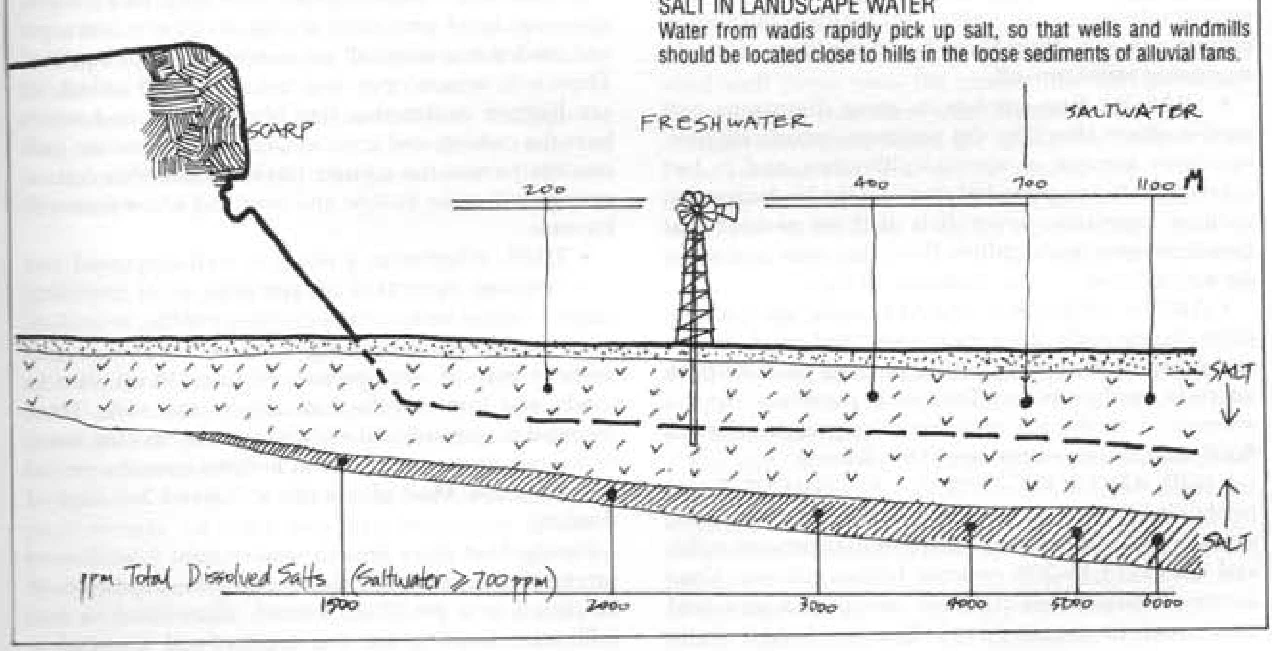


FIGURE 11.34
SALT IN LANDSCAPE WATER
Water from wadis rapidly pick up salt, so that wells and windmills should be located close to hills in the loose sediments of alluvial fans.

TABLE 11.3
PRECIPITATION INTENSITY

mm/day	EXAMPLES AND PHENOMENA
0-10	Light dews (0.8), light rains in semi–arid areas (4), prairie rains (6). The smallest rills commence flow at 6–10 mm.
11–20	All day drizzle (12), sheet erosion can occur at 13, gully erosion can develop at 15. Diversion drains in first and second order streams will flow. Typical of rains of humid coasts, warm frontal air masses.
21–50	Typical of monsoon sloud streets on coasts, or light rain all day in western maritime climates, and periods of convectional rain in deserts.
51–100	The condensation drip from onshore fogs (60 mm); tropical rains exceed 100 mm once a year.
100–200+	Heavy rain all day, and exceeded once a year on monsoon coasts, tradewind coasts. Exceededonce per century in temperate maritime areas.

TABLE 11.4
RUN–OFF FROM VARIOUS SUBSTRATES.

% RUN–OFF	SUBSTRATES
0	Coarse sands, active dunes, fixed dunes in dune seas.
5	Forested.
10	Wooded and grassed areas, tussock grassland.
15	Cultivated sands and sandy loams.
20	Approximate average figure for semi–arid and arid areas.
25	Ungrazed steppe of mixed shrubs, forbs, grasses.
30	Drained and cultivated clays and clay loams.
40	Steppe and shrubland grazed by hoofed animals.
50	Undrained clays, claypans,urban roaded areas.
60	Skeletal soils and scattered vegetation.
70–98	Compacted soils, solonetic soils, non–wetting sands, extensive paved areas, full water storages.

rangelands, run–off decreases. However, it rises rapidly as perennial prairie or tussock grass is in turn replaced by burnt ground or grazed–out areas where only ephemerals or annual grasses can flourish. Burning of clump grasses, therefore, has a sudden effect in increasing water run–off.

• SEASON. Run–off has its most disastrous and erosive effects after long dry summers, broadscale fires, extensive autumn or spring cultivation, and in fact subsequent to any period of stress on the landscape that reduces vegetative cover. It is at these periods that thunderstorms create gullies, flood thin soils, and cause the soil collapse that can create salted soils.

• ARTIFICIALLY SEALED AREAS. Roads, parking areas, house roofs, bare rock, concreted open drains, and compacted areas of settlements all produce flash floods in nearby streams. The area of these total run–off systems in catchment must be calculated if effective flood retardation systems are to be planned.

• SOIL AND ROCK TYPE IN CATCHMENT. Rapid rainfall infiltration occurs only in coarse or open sands, sandy loams, kraznozems (deep, well–structured soils), and soils with 15–20% or more humus content. Non–wetting sands, sealed clay soils, compacted soils, and sheet rock or massive rock domes all shed water rapidly. Areas of each type need to be mapped or noted in the catchment under study.

Gravels and boulder–banks, shattered rock ridges, unconsolidated pediment wastes, limestone outcrops, and eroded fold crests all act as *intake areas* for aquifers. These will remain open and reduce run–off unless (as can happen in deserts), fine blown dusts and sands bury the crevices and boulders, or wash down into rock crevices to seal the aquifer intakes. Once this occurs, springs will cease to flow and overland water flow will increase.

• TIME. Whether as a result of well–dispersed and low–intensity rains (1–2 cm per day), or of impeding surface factors such as tussock, litter, pebble, or artifical pitting and contour banking, water will soak into soils without run–off over periods of from 30 minutes in sands, and from 3–4 days in clay–fraction soils. Thus, we need larger artificial storage capacity in clay areas, or we risk drowning plants in hollows over the period of infiltration. Most plants can withstand 2–3 days of flooding.

Ideally, best plant growth results from 0.5–1.2 m of saturated soil, and infiltration rates of this depth should be timed in a pit (first wetted, then filled to test infiltration time) so that this depth of soil is wetted in something less than 48 hours. Given this data, the width and depth of total interception by swales or banks can be calculated, and retardation basins built to reduce water loss, increase vegetation, and control floods. These artifical intakes are now necessary over very large acres of overgrazed and eroded country.

• WATER VISCOSITY. Water density is little affected by temperature, while temperature has significant effects on water *viscosity*, hence on streamline shear or "friction". Day-time rains on warm surfaces run-off faster than night rains, or rain in cool night periods. As many deserts encounter rain in summer (monsoon) regimes, floods peak earlier in these regions than they do in winter-rain areas. Both the velocity of flow (the main erosive factor) and turbulence are accentuated by warmth and lower viscosity. Viscous water may cause local water level rise in low-order streams at night, and support heavier floating loads of detritus.

In many areas, local long-term stream guaging will not exist. The best guide to past flooding levels is therefore careful observation, based on damage to trees, old detritus levels, flood detritus caught up in trees, local knowledge, and a sensible assessment of the catchment area, its type, and rainfall data from similar regions.

Any designer can, by reference to rain days, catchment area, and a set of the foregoing factors, make an estimate of the potential for run-off (as overland flow) in a specific locality. Thus an estimate of the potential storages needed can also be made, so that loss of water off-site is eliminated or reduced.

Run-off in deserts, depending on the permeability of the surface, ranges from 5–80% of rainfall. Averages may be low, but in flash floods (not uncommon in the total precipitation), higher percentages are obtained. I have seen diversion channels in stable non-wetting dunes flowing as small streams in 1 cm of rain, and these filling large storages in a day. We can accept about 20% as an average of run-off, but in practice it is safer to allow a 20 ha run-off area to 1 hectare of crop, or cultivated vegetation, to ensure sufficient soakage for long-term growth. Only in areas of reliable rains can we reduce this ratio to 15:1 (catchment area to field area or productive crop).

HALTING AND ABSORBING WATER RUN-OFF

The halting and absorption of run-off has two main aims: to convert water from a destructive erosion force into a quieter life-creative energy (to develop forests), and to recharge groundwaters so that freshwater sheets develop above the deeper saltwater leads of the desert, and trees can benefit.

However, we should always do our sums and keep good records, for if we withdraw freshwater from the groundwater storage faster than we can recharge it, we are only temporary inhabitants of the desert. Thus our uses must be frugal, needful, and devoted primarily to establishing deep-rooted and drought-resistant trees, not to supply wasteful lawns, flush toilets, and leaky pipes!

Wherever we establish a surface intake from run-off steams, we may risk silt clogging. If we design a broad intake, with trees on the outer banks, we can use this silt (and any cover crop we sow on it) as a rich side-dressing to trees. For a check on silt depth, it may be wise to place permanent steel pegs with clear graduations in swales, and to sow and grade off at any time that more than 20 cm of silt is deposited. If only hand labour is available, such silt removal requires swales not exceeding 4–5 m wide, but with a tractor and blade (or road grader), swales can be 5–18 m wide. Infiltration can be aided by ripping the swale base, and using gypsum in clay soils.

Should low slope soils themselves be subject to steady erosion, swale banks can be exaggerated in this way to form eventual terraces, with trees now on the outer terrace slopes. Such evolutions occur where the slopes are sandy, or where cultivation takes place on the slopes between swales. As terraces (with treed edges), the slopes stabilise, and silt removal is a less pressing necessity. Such terraces are not a continuous series, but spaced downhill at intervals of 20 times their width.

By a succession of such strategies, large and small, desert groundwaters can be compelled to sustain a recharge. It is quite possible to create springs and to maintain low streamflow if a succession of 5–7 swales are made to behave effectively on run-off slopes; such effects occur naturally where once-full lakes such as Pyramid Lake, Nevada, receded in a stepped succession, leaving 1 m deep and 3–6 m wide bands of "beach boulders" across the slopes, and so halting run-off. Below these bands but above the present lake level, freshwater springs occur.

Bleed-off systems for turbulant and silt-laden streams can tax our ingenuity. In every case, a *restricted* water exit should open into a much *wider* drain (the silt trap), which later leads into a broad reed bed, from which fairly clear water can be led to a dam or swale sited well away from the stream line itself, and not above a valley settlement area (**Figure 11.14**).

While dams store water for village use, swales from these systems can be a few kilometres long (they can reach to the next fast stream) and can therefore grow extensive forest lines with no more trouble than an occasional silt clearing and a few hours with a road grader. Seasonal silt clearing in the silt trap may be necessary until trees are well established.

If heavy machinery (and very large stones) are available, a more substantial dam can be built, allowed to silt up, and a water channel cut from the level area just before the dam.

The aim, however, is clear: it is to lead run-off on contour to absorption or soil storages before it flows out to the salt flats and is made useless. For minor flows, a simple swale suffices to direct and absorb sheet waters. Even dam spillways in deserts can be led from the rear of the dam into long swales before being spilt into minor streams. We can hold thousands of times more

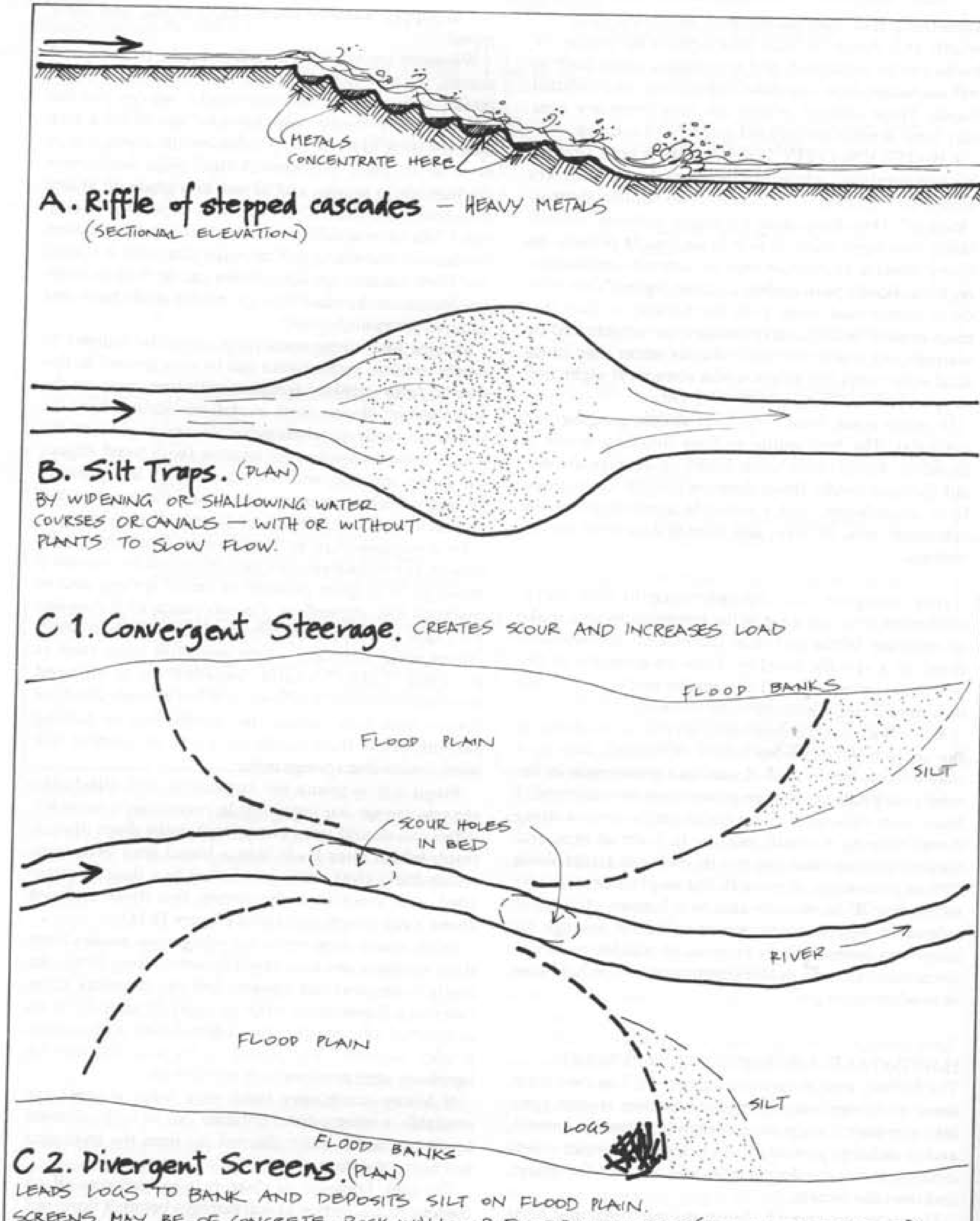


FIGURE 11.35
DESIGNS FOR SORTING PREFERRED SOLIDS.
Rivers, canals, flood plains, and diversion drains can be sculpted to deposit a variety of loads where these are useful, near gardens of houses. Silt traps may be needed in most deserts. See FIGURE 11.40 for details of flood plain fences.

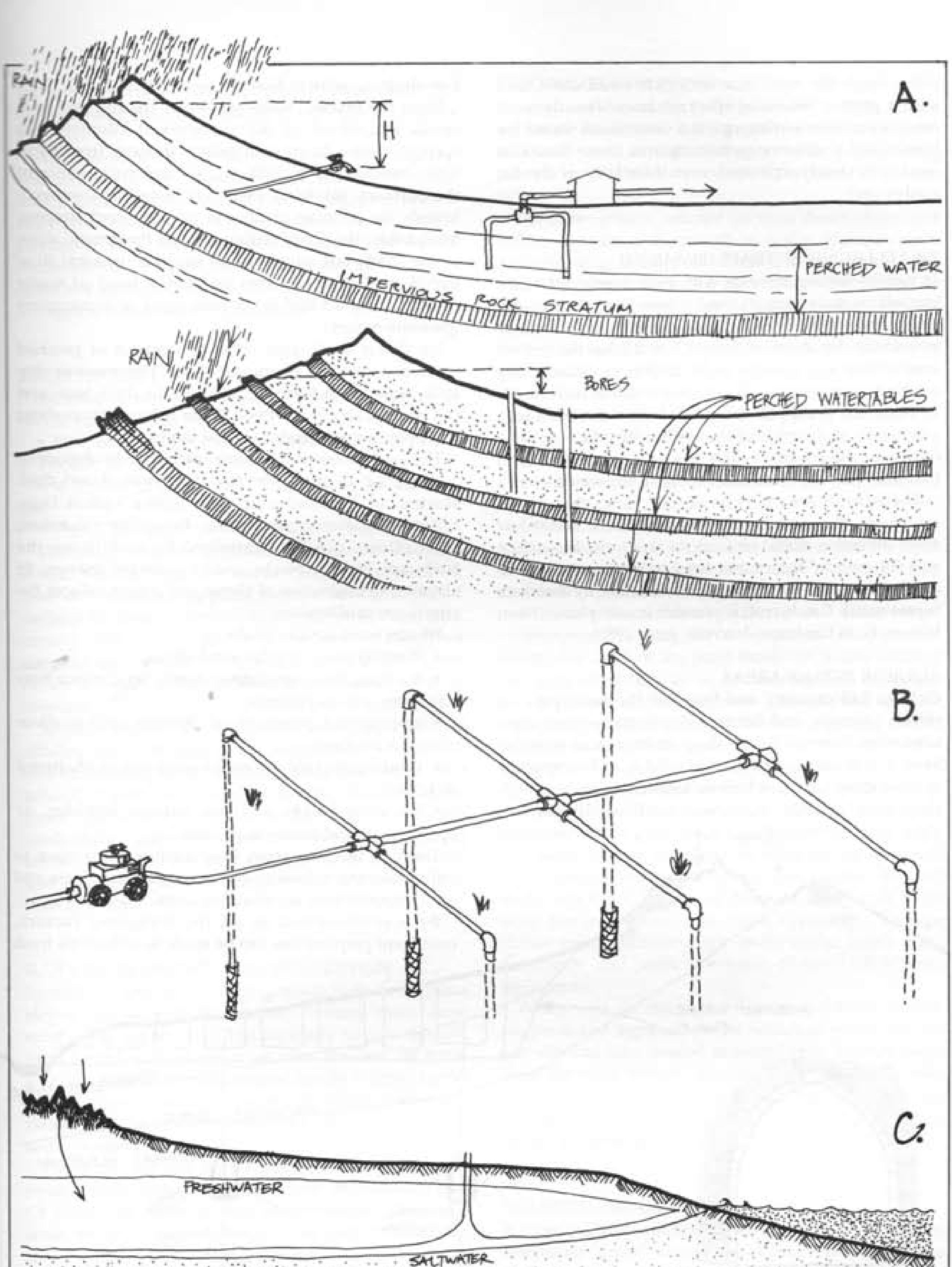


FIGURE 11.36
AQUIFER INTAKE AREAS.

A. Fold sediments may create a series of aquifers above impermeable layers; slant–bores can tap some of these at head by gravity flow.
B. A manifold of 50 mm pipe and filters is ideal for shallow sand pumping.
C. Deep bore wells may draw saltwater table up to pollute surface soils.

water inside the earth than we can in small dams, and with a greater beneficial effect on trees. Two dams of modest size near a village gives a clean water source for houses and a welcome swimming area (these functions need to be clearly separated, even if the latter is also for garden use).

ISRAELI RUN-OFF TRAPS *(LIMANIM)*

In gently-sloping uplands with well-developed valley run-off in rainy periods, and where loess soils enable deep infiltration, Israel has developed what are essentially dry dams of from 0.1 to 0.5 ha, the bottom graded flat, and the dry walls little consolidated. The banks themselves are 1-2 m high and 2-5 m wide. It can be beneficial to support the inside base of the bank with stone. Sills at the ends of the walls will spill water at a depth of 40-60 cm, when it can flow to the next *limanim*. Trees are established in these impoundments.

The run-off area is from 30-500 times that of the catchment. The more gently water can be led in (via low slope diversion drains or as sheet flow), the less silting and sill erosion occurs, but trees will grow well if the soil is kept open by tillage, or compaction by livestock is prevented. Catch-crop is possible in wet years. (From Wilson, G. in *Landscape Australia*, Aug. 1980).

AQUIFER INTAKE AREAS

Only in hill country, and then for the most part on ridges, plateaus, and detritus slopes do we find open subsurface channels for the deep infiltration of water, as loose gravel ridges, shattered or soluble rocks, cappings of loose dune sands, or heavily forested ridges and high slopes of porous materials such as limestone, free-draining soils, or fissured rock (**Figure 11.36**).

From the intakes, water will enter the soil and rock strata, and travel for many metres or kilometers to springs, rivers, or artesian basins. If water from these latter sources is to be utilised, care and maintenance of the primary intake is essential. Satellite telemetry reveals the patterns of flow in underground streams. Most follow the dip of sediments, and the general slope of the land, but aquifers can (unlike streams) flow uphill, and they can also produce a head of water (usually from 0.5 to 7 m) in bore pipes or piezometers (pressure meters).

On flatter land, large areas of sand act as perched aquifers above less permeable desert pavement or clay soils. Water from these seeps out of the dune base, and can be used locally for trees. Water is found from about 2 m deep in dune sands as moist sands.

The intake areas can become ineffective by deposit of volcanic ash or mud, by fine dust from desert dust storms, or by sand and dust blown uphill from cultivated and overgrazed areas. Except for vulcanism, such effects can be minimised by stabilising the landscape, by windbreaks, and by protected reserves. In all cases, deforestation of slopes and ridges reduces the effectiveness of intakes.

We can assist aquifer intake by:

- Planting trees on ridges and slopes;
- Building deep interceptor drains on contour near ridge tops and on plateaus;
- Ripping rock pavement or capstone areas to allow water penetration;
- Leading surface drains to wells cut in shattered rock; and
- Creating banks of loose surface boulder, or opening pits and swales in gravels.

Trees, in the long term, keep such systems open to infiltration and reduce or eliminate dust from loess and sand deposits from surrounding areas.

By a combination of all the foregoing factors, intelligent preparations can be made to utilise this fresh

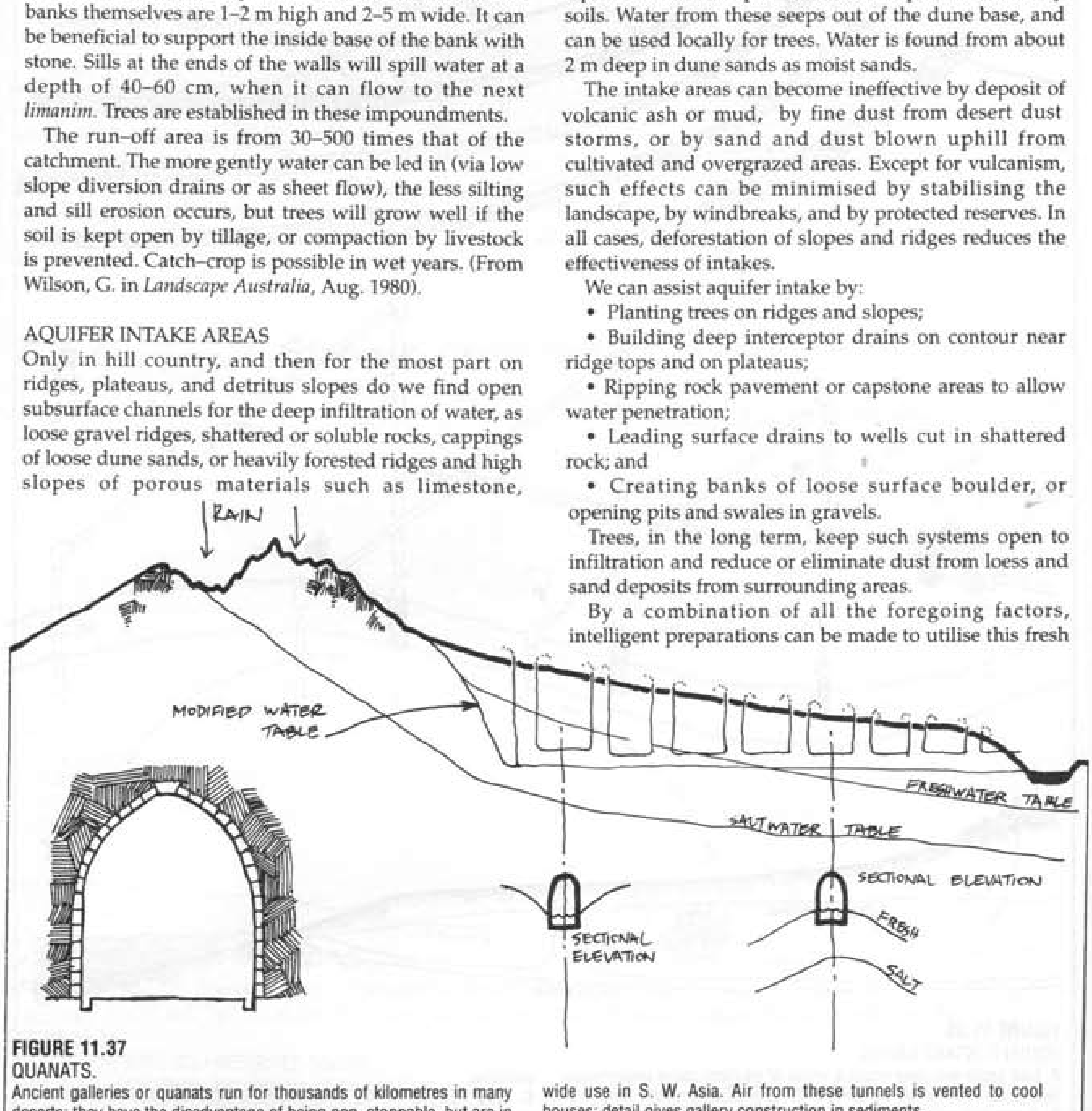


FIGURE 11.37
QUANATS.
Ancient galleries or quanats run for thousands of kilometres in many deserts; they have the disadvantage of being non-stoppable, but are in wide use in S. W. Asia. Air from these tunnels is vented to cool houses; detail gives gallery construction in sediments.

water where it does occur. QUANATS have been used in the Middle East for centuries to tap aquifers (**Figure 11.37**).

When areas were forested, ungrazed, uncultivated, and lacked the hard pavements of roads and settlements, little run–off occurred and throughflow in soils kept streams flowing. Desertified areas lack these characteristics, and we need to intercede in the hydrological cycle to store, infiltrate, and convert rainwater to vegetative growth—in short, to create soil storages to assist forest regeneration.

INFILTRATION

Infiltration of water and the time taken to infiltrate 25 mm of rain (in hours):

- 11–7 mm/hr minimum in sands and dust (loess) 2–3 hours;
- 4–1 mm/hr minimum in clay–loams 6–20 hours; and
- 1 mm/hr in alkaline swelling clays 24 hours.

This has quite a few implications for us, for if we can spread neutral or acidic sands about 0.5 m deep or more over alkaline clay pans, then we have an excellent surface to first infiltrate and then hold rain, and consequently a good garden or tree site, on which we can store up to 1 m of water for long periods. This effect occurs naturally at the discharge end of some gullies or canyons.

Another way to achieve this is to open deep swales in alkaline soils in front of sands and gravels on the move, and let them fill. In many areas, people have (with great labour) buried layers of clay, plastic, thick colloidal green matter (gley) and tar or latex under the deep sands of their gardens; on the broad-scale, drainage slits are left every 100–200 m in these systems. It is obvious that we need to hold water for a day or more for it to soak in to soils.

SLOPE STABILISATION FOR INFILTRATION

Spinifex or porcupine–type grasses help to stabilise slopes and increase infiltration, forming cross–slope sand dams as they age. The normally circular tussock form breaks open to create an open crescent, its horns uphill. Detritus forms deeper sandy rubble banks behind these lunulate clumps, effectively creating a swale. Burning destroys this effect and allows sudden slope erosion to occur.

However, we can create such infiltration aids as swales, wadi dams, levelled gardens, and soakage pits. Of these, the swale is most easily created on a large scale, but wadi dams may also work well for local food forests; neither are a trouble if some basic machinery is available. In cold deserts, tussock grasses and mosses perform the same function for unstable rock slopes and soil flows, and cross–slope Vetiver grass lines on contour greatly assist water infiltration and slope stability.

FLOODWATER HARVESTING

Aboriginal Australians (Stevenson, 1978) made earthwall floodwater dams to increase *Panicum* grass and their seed, as did the Papago and neighbouring groups in the Sonora regions of the USA (Nabham, 1979).

The latter groups worked on river flood–plains and deltaic deposits at the mouth of wadis. Nabham notes the interesting fact that although summer storms bring 40–60% of water, they add only 15% of the run–off to mainstream resevoirs. Most of the run–off is localised in intermittent streams, and is only available for local headwater agriculture. About 8 cm of rain is needed to give useful run–off, over a catchment area 15–27 times the area of fields. Hardy crops such as sorghum are produced with run–off only 4 times that of the field.

Along the Colorado River, floodplain fields were also constructed for major floods. Techniques cover temporary basins, irrigation canals, and field boundaries of stone and earth reinforced with posts, brush, and vegetation. Planted and wild or weed species are grown together as a crop complex over 4 ha or less per field. The system is part of that illustrated in **Figure 11.40**, and needs minimal management.

As headwater streams coalesce and enter broad valley systems flowing out of the ranges, broad braided rivers (dry most of the year) break out across country, dropping silt as they do so, and leaving lines of organic mulch at their highwater level. This mixture of seed, manure, twigs, molluscs, and debris is excellent garden material and can be trapped using a sequence of stout scoop fences (**Figure 11.40**) for use in gardens.

Where the land flooded is flattish, a "grid–iron" of low banks keeps the floodwater and silts settled and absorbed. Such grids need banks only 0.5–1 m high, and those are best stabilised by stone on the upstream side, tussock grasses or tough low shrubs, live–set sticks and brush, or can be made of heavy rock walls from the main river bed. Such systems in Papago Indian areas maintain high levels of the major plant nutrients, and were the basis of the rich Nilotic agriculture.

When and as the river floods, fields of millet, sorghum and legumes can be broadcast sown into the wet silt, and later headed as stored crop. Further away from the main stream, broader deep dykes will hold waters in narrower and deeper channels for tree crops, and the trees should overshade the deep absorption swales so developed.

BRAIDED STREAMS

A close study of braiding patterns in streams, and in the associated "green" areas of vegetation, showing up as darker areas on a black and white photo, reveals that there is an inverse relationship between the land areas wetted or saturated and the channel width. Small multiple streams produce much larger wetted areas than simple main channels (**Figure 11.38.A**). This suggests an as yet untried strategy where (in dry periods) we can build concreted, deeply bedded, deflections in main channels, and set these out to split the flood flow as often as we have space to create small channels (and there is ample space in most arid flatland flood plains).

In effect, we are trying to *widen* and *slow* the floodwaters, and wet as much alluvium as possible. As such floods more frequently arise from headwater run–off, not local rain, it is in our interest to spread and harvest such water before it is lost to saltpans in the desert (**Figure 11.38.B**).

Methods of achieving multiple stream braiding would be best modelled in experimental sand channel flows, but the ground effects on vegetative growth are evident in many arid areas, when the wetted areas support strong tree growth.

The process of braiding depends on a shallow water flow over extensive deep sand sheets; braiding does not occur "underwater". Each braid–form is initially a diamond (rather, a rough diamond) with plunge–pools at each corner, caused by the confluence of side streams. Ideally, the unit forms are as in **Figure 11.39**.

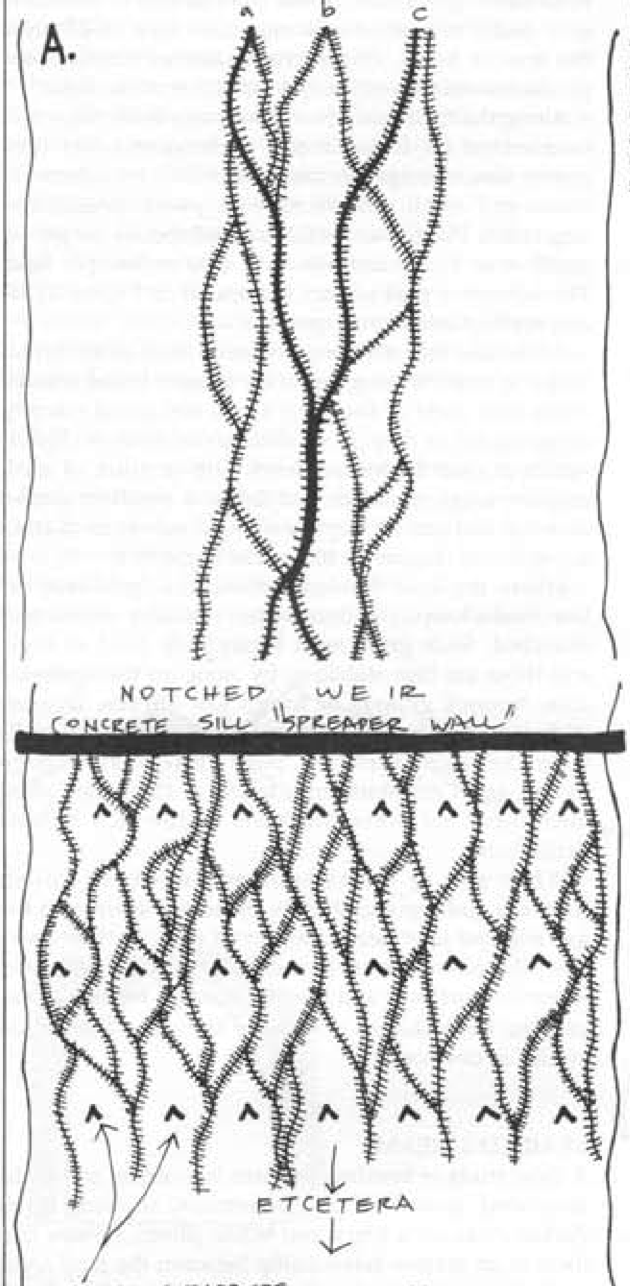
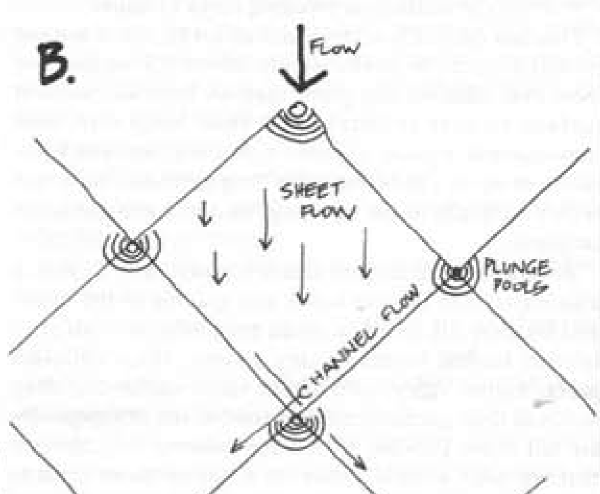


FIGURE 11.38.
A BRAIDED STREAM.
A natural braid occurs in sand beds at the centre of flood plains.
B NOTCHED WEIRS
can spread flood braiding across a full flood plain; hatched areas show absorption areas where trees and shrubs will grow (see detail).
C. Details of braid patterns in sand, notched weir to initiate braiding in sandy rivers.



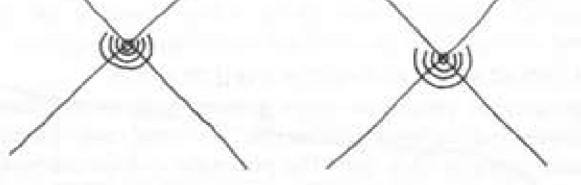


FIGURE 11.39
NOTCHED WEIR (Elevation).

In low flow conditions, only the channel flow persists, and sheet flow across the interfluve is absent. Just what initiates the pattern is not clear, although similar flow patterns arise from scattered pebbles or shells in sand. However, I believe that we could spread floodwaters more fully across plains, initiate a finer mesh of the pattern, and spread and absorb water effectively if we erected a level, notched wall across the braided area. The notches are in effect the imitation ofplunge pools.

SCOUR HOLES

Within 10–50 km of ranges there may be a few permanent desert lagoons. They are often of great beauty, full of crustaceans, fish, molluscs and water plants such as lotus, kangkong, water chestnut, and submerged weed. Birds and mammals visit by day and night. How do these lagoons form?

In every case, they arise from a strong natural ridge (often unnoticed by visitors) that approaches the river from one or both banks, thus constricting the flood flow and forcing an increase in velocity and a powerful hydraulic digging action. These days, it is simple enough to replace or construct such ridges using a combination of rock–cement walls and a bulldozed bank, stronger and deeper near the river bed itself. The ponds remain full in drought only because the deep sands of the river contain millions of litres of slow seepage (which we can also increase by installing sand dams higher up in the system). Nevertheless, we

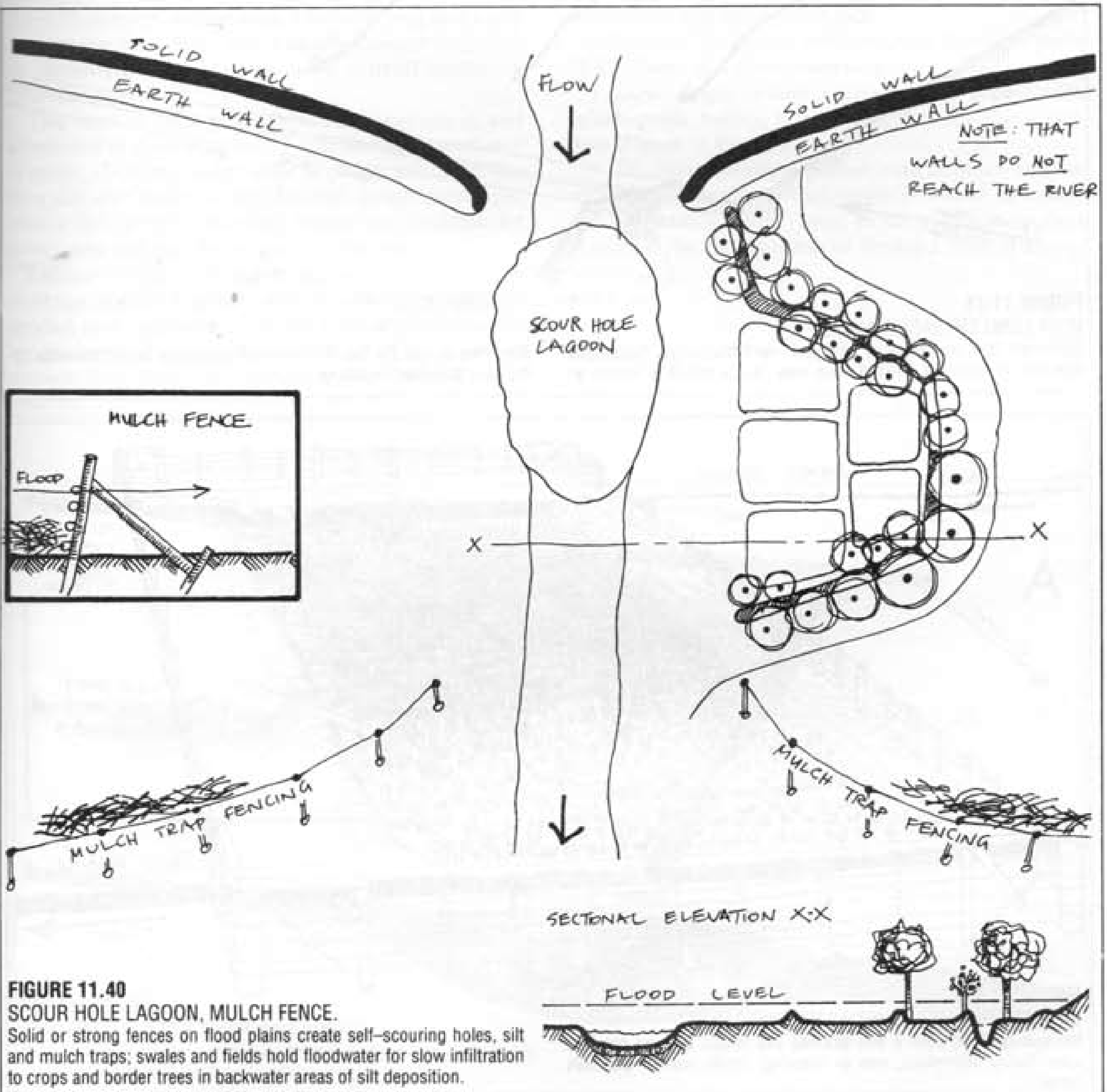


FIGURE 11.40
SCOUR HOLE LAGOON, MULCH FENCE.
Solid or strong fences on flood plains create self–scouring holes, silt and mulch traps; swales and fields hold floodwater for slow infiltration to crops and border trees in backwater areas of silt deposition.

should not create these open–water systems too frequently *unless* we have made silt dams of up to 9 or 10 times the capacity of each pool, as open water will evaporate over time. The profile of such natural scour beds is as in **Figure 11.40**.

SANDY RIVER BEDS

Wherever deep sands fill rivers, palms and large trees will stand in small embayments off the river, where flow damage to their trunks is less likely. A good guide is to observe how native trees survive, and where the largest trees grow (that is, if cattle have not killed out the range).

It is very noticeable that desert river banks in hills will often have quite separate species of trees on either bank; this may be true of all rivers eroding country areas. One species needs the slip–off or silty slope, the other thrives on the harder country rock of the erosion bank. Almost all the burrowing animals use the silted or slip–off slope of the river.

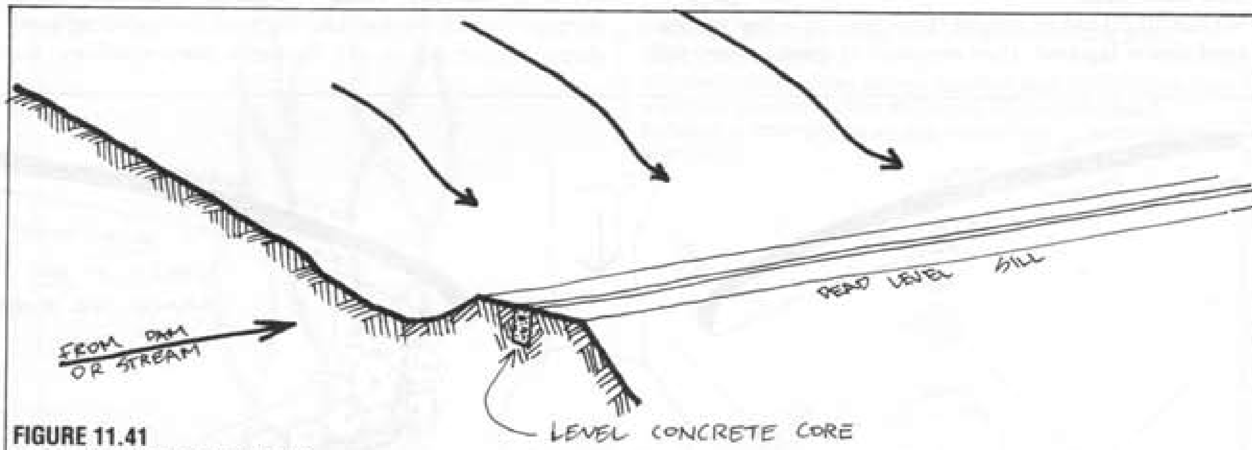


FIGURE 11.41
VERY LONG SPREADER BANKS.
Spreaders take concentrated flow and sheet the waters harmlessly downhill. In inportant areas, a solid core can be added to ensure an even flow across the hill. A cross–wall eventually blocks the ends of the bank to prevent discharge.

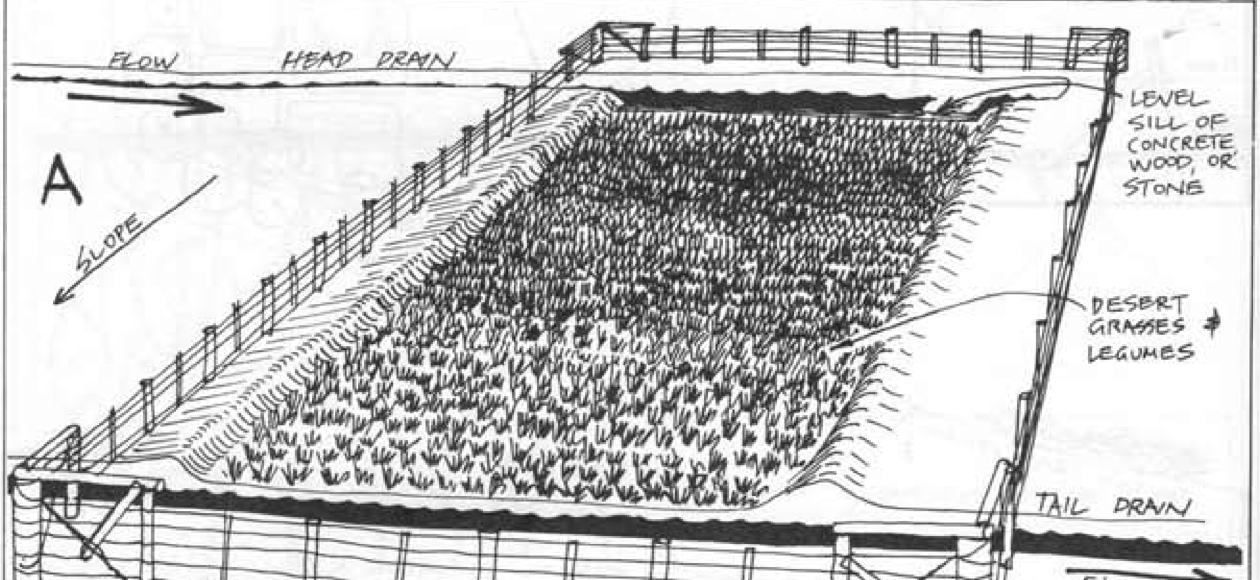


FIGURE 11.42
GRASSED SPILLWAYS WITH STEERING BANKS.
Below a spreader bank a well–grassed and fenced spillway can lead water safely downslope; side or "steering" banks prevent sideways spread.

PITTING IN SANDS AND LIGHT SOILS

By cutting a quarter-section slice off a set of disc blades, "long" pits are made, with a quarter of their length as solid breaks. As discs are drawn along, we get a series of mini-swales, and these too are staggered, like our contour swales.

A great advantage is that such short pits or furrows need not be strictly on contour, so that they can be drawn by eye. No one pit is so large as to spill too much water and cause stream flow. Seed can be added to pits, broadcast, or blown in from residual vegetation. The method is fast, effective, and can be completed on the broadscale; grasses, shrubs, trees, and forbs can be seeded.

These pits effectively become small swales for an area of bare soil. Over many acres, they have enormous storage capacity. They would usually be spaced at 0.5–0.75 m apart, and be from 1.0–1.5 m long and 0.3 m deep at the most. Here, soil is ideally sidecast downhill, or downwind, but this is not a critical factor on near-flat sites.

This form of discing acts as surface roughening, and eliminates or greatly decreases dust storms as soon as it is made. There are many forms of pitting machines, but they can also be hand-dug. Pelleted desert shrub seed plus a light fertiliser dressing creates the condition for permanent soil stability around settlements.

Cordon (1975), working in semi-arid hills, records average annual run-off of 20%, with up to 80% in eroded and compacted soils for individual rivers. He recommends (for slopes in excess of 2%) a series of contour furrows or mini-swales at 2 m intervals, with only every 20–30 contours actually surveyed. The swales are "broken" to allow flooding through to the next series. Vegetation in the furrows remains green in drought. The soil chosen for these systems must have the capacity to absorb the moisture (which mean soils primarily of sand). The scale and area treated can be as large as is required at the 2–4 m spacing.

SPILLING WATER DOWNSLOPE IN FRAGILE SOILS

Steep-sided gullies often result from road culverts, animal tracks out of wadis, or water discharged from diversion drains after fields are flooded.

There are only a few safe ways to spill downslope in deserts; these are:

- Very long spreader-banks (**Figure 11.41**), maintained and inspected in rain.
- Grassed spillways with steering banks (**Figure 11.42**). These take a few years to evolve.
- Downslope sealed spillways or pipes with splash-pools, leading to a swale, one of the above, or a dam (**Figure 11.43**).
- "U"-shaped channels filled with boulder, smaller rock, then gravels, so that water is forced to follow multiple stable paths.These, in fact, imitate in their structure the rock sorting of dryland breccia slopes below cliffs.

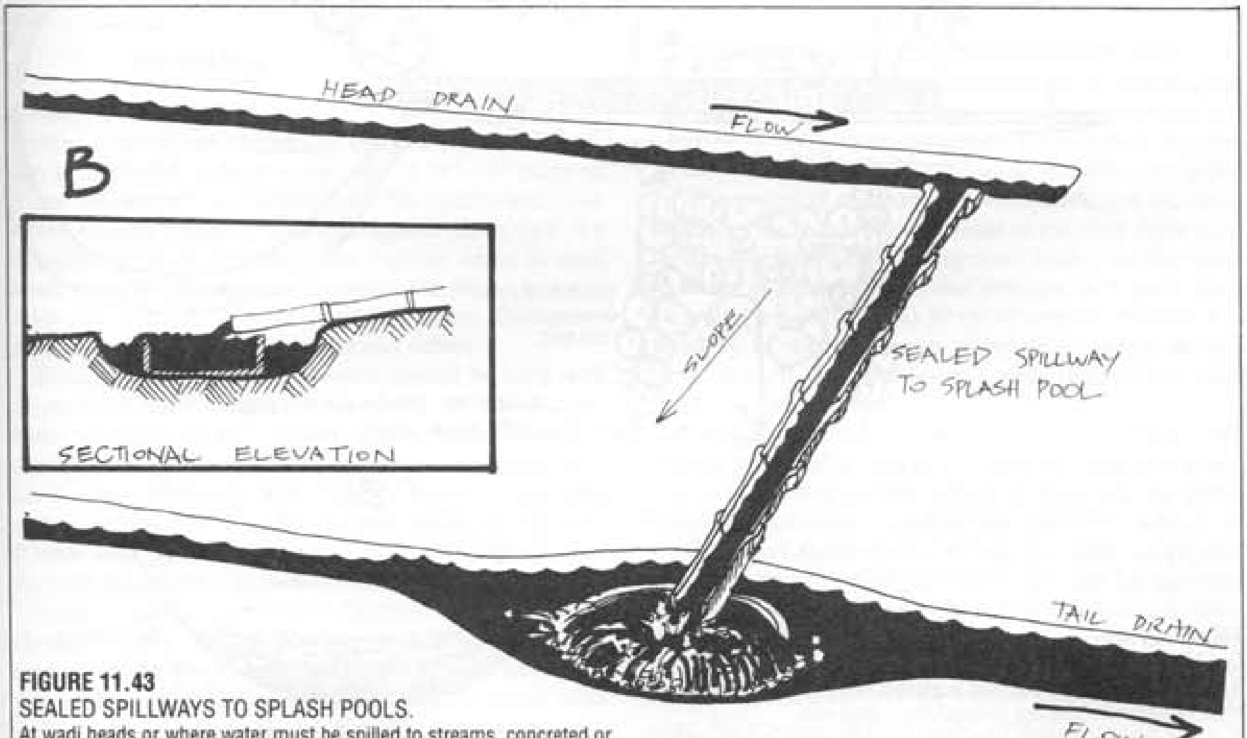


FIGURE 11.43
SEALED SPILLWAYS TO SPLASH POOLS.
At wadi heads or where water must be spilled to streams, concreted or stone spillways and splash pools quieten erosive effects.

SAND DAMS AND CLEARWATER RESEVOIRS

Washes in gently-rolling foothills carry broad floodwater surges. It is very advantageous to dam these so that water backs up 10–20 times the dam width. The wall must be keyed in for 4–6 m to the side banks, or water will scour around the ends. Before this is built, it is necessary to cut a series of 2 m deep bays into the upstream banks, and to have several loads of coarse stone to place against the upstream side of the wall itself. This will form a drain to a clearwater dam, which itself should be less than a ninth of the total area backed up by the wall (**Figure 11.44**).

How it functions is fairly simple. The first floods rush down and over the wall. Silt and coarse sands fall out and in a few rains fill up the storage. The shingle or rocks on the inside of the wall act as a filtered seepage to the clearwater dam. The dam itself also leaks water through the river bed—it is intended to— and some

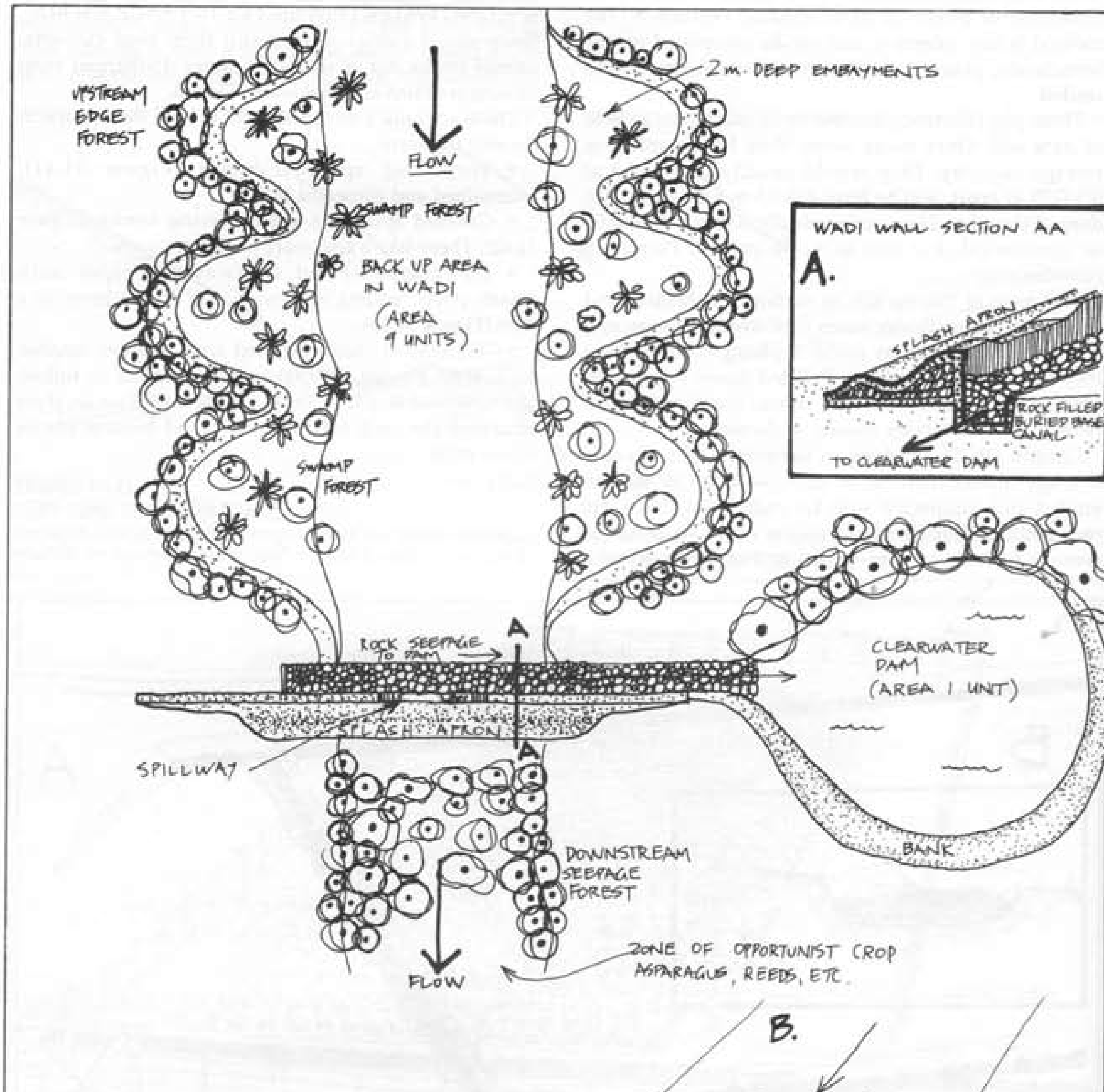


FIGURE 11.44
CLEARWATER DAM.
A. wall; silt field above this wall is planted to trees and opportunistic crop. Downstream seepage creates forest below wall.
B. A safe downhill spillway from dams must be carefully constructed, over-sized, "U"-shaped, otherwise gulley erosion occurs.

water seeps through to the downstream forest. The bays we dug upstream also fill with sand and make a flat water-filled silt bed on the edges of which we plant valuable large trees (pecan, palm, avocado, mango) which make up the upstream forest. Such trees can also surround the clearwater dam (the dam forest).

When the barrier dam is sand-filled, several deep rooted sub-aquatics will grow there, e.g. asparagus, *Mauritia* palms, Chinese water chestnut, swamp cherimoya, etc. Full, the rubble and sand act as a buried water resevoir which keeps the dam full (I know of one such dam that dropped only 8 cm in level over a 7-year drought), and also as a deep reserve of moist sand for trees. The downsteam forest may extend 1–2 km in the deep sands of the river (for a wall only 50 m wide).

There are hundreds or thousands of such sites a few kilometres from foothills in deserts, and this simple but sophisticated system creates oases where there were none before. The figure shows a dam built by a railway engineer at Oodnadatta, South Australia, in the 1920's; it is still functioning well in the 1980's.

Below roost trees around such dams, the guano from desert birds may be gathered as sheets of phosphate fertiliser, and these are of great value in establishing dune or rock windrow trees (as a dilute solution or mixed with 30–40 parts of damp sand). On the silt dam, melons grow very well as the first swampy condition recedes, and a good crop of legumes and melons can be planted at that time. A few such dams support a strong village population, and will keep scour holes downstream recharged with water for swimming holes. All clearwater dams should be 5–9 m deep and of reduced surface area, rather than shallow and wide.

DAMS

Barrier dams across streams in wooded and stable hills can be expected to have a long life of 100–300 years or more, before silt and humus fill the catchment, and even before then a well-designed dam can be silt-flushed from the base. But barrier dams in arid areas must be planned from the outset to fill to the brim with silt and rubble in the first few years. The water they hold will be stored *in* sands and rubble.

Thus, *clearwater* dams in deserts should be built well away from such valley sites, and the turbulent flow from wadis or foothill sand-bed and boulder streams must be bled off into almost-level channels fitted with sand traps, and only after that to a dam. This dam should not itself be sited so that fast water can run in to it over loose surface material. It should be fenced, and the margins planted to rushes and shrubs. **Figure 11.45**.

Some helpful factors for an effective sand dam can be checked before construction begins. Ideally, the rubble and silt in the dry creek bed should be very open and permeable, of stones, pebbles, and coarse sands (this will almost certainly mean that the dam is near the foothills or in a valley close to the headwater rocks). Secondly, the floor of the dam is ideally clay or massive rock, and hence leak-proof. However, even if neither of these factors are ideal, sand dams will still be good growing sites, as we will be slowing down flood water on a long and level site.

An extensive silt dam of 9–12 m in height is always built in 1.5 to 2 m stages, and the wall raised as the earlier stages silt up. Behind each wall, gabions allow water to filter down to a base pipe, which can be led to settlement. The whole area of such catchment needs to be protected from sprays, fertilisers, and browsing animals to protect health in settlements.

ROCKHOLES AND GNAMMAS

Rock basins, often filled with water, arise from a series of origins; some are:

- Rock scouring in stream flow (corrosion) on stream beds.
- Freeze-thaw and wet-dry swelling and shrinking plus rock mineral hydration.
- Salt-eroded ponds in rock, as near the sea.

There are many ways to assist water conservation in rockholes, e.g.

- Fill hole with pebbles to lower evaporation; some water is lost.
- Thatch or cover hole.
- Build gutters to hole.
- Erect a metal mesh fence to direct dew condensation to hole.
- Deepen hole, and plaster it with cement if it leaks.

EVAPORATION AND EVAPOTRANSPIRATION

As we have defined the climatic scope of this chapter, open-pan evaporation (pans of water exposed to air) will always exceed or equal precipation over the year. In fact, almost all of the sub-humid to arid areas tested have a potential evaporation well above that of actual rainfall. This means that for most of the year, there is no longer any free water to evaporate except for the water in dams or other open-water storages. A typical grain crop such as millet needs 50 cm of water to mature. It is unlikely to obtain enough water *unless* water storage from run-off is available, or unless run-off has been infiltrated into the soil.

Direct evaporation in still air (the "oasis effect") will exceed potentially 100 cm per year in most arid areas, but a far more severe effect is that of hot wind evaporation (the "clothesline effect"), which in unsheltered fields most effects the field edge and increases transpiration 10%–30% over the background effects. Chang (1968) records that winds blowing from arid to humid areas may affect crops or trees for 400 m before acquiring a non-evaporative water moisture load. In effect, a 400 m wide evaporation border of trees may be needed between the desert and productive croplands. There is no doubt that a windbreak of trees uses less water than that removed by the hot winds over crop, so that throughout croplands, scattered trees and cross-wind tree breaks are essential.

Needless to say, such trees should be selected to be both dry-adapted and of benefit to the crop. *Acacias*, such as *A. albida*, and *Prosopis spp.*, are some of those commonly used to protect and benefit crops in arid areas. Evaporation from open pans of water outside the crop or tree shelter can be 16 mm/day, while 300 m into the crop, only 5 mm/day is lost. In this case, the crop itself acts as windbreak, with a consequent gain in yield due to less evaporation. Whatever we can do to prevent the drying effects of hot desert winds will be worthwhile, so that although we will always be left with an oasis effect we need not suffer extra loss of water. For restricted areas of crop, narrow canals, or home gardens, we can screen out winds and shade the area either with shade cloth (to 50% or more shade), vine crop, or the canopy of palms and "umbrella" *Acacias*. These strategies plus ground mulch drastically reduce the water lost to evaporation from open storages and crop species.

CONSERVATION OF WATER IN TRANSIT

The transmission of water (as with any fluid or gas) needs great care. More water can be lost in canals, especially in loose soils or shattered rock, than is lost in use. Even open concrete channels can lose great quantities of water to air. There is really no substitute for long runs of pipe, and in small systems extruded PVC (flexible or rigid) pipe is most effective. Runs of 100 m or more can be made in one length; there are now long rolls of collapsible pipe for surface use, which can be unrolled as needed.

There is one other way to store water from opportunistic run-off, and that is in tough plastic or neoprene bags. These can, like swales, operate from fixed-diameter pipe inlets, much as the feeder drains operate from a head drain. The swale in this case is provided with a rolled container, which fills and unrolls as water fills it, and forms a "sausage" along the swale. Precisely the same technique can be used to capture fresh water flowing into salt lakes, so that the freshwater sausage floats, and is available as unmixed water on demand. This can be a much bulkier article, with greater depth/width ratio, as there is no

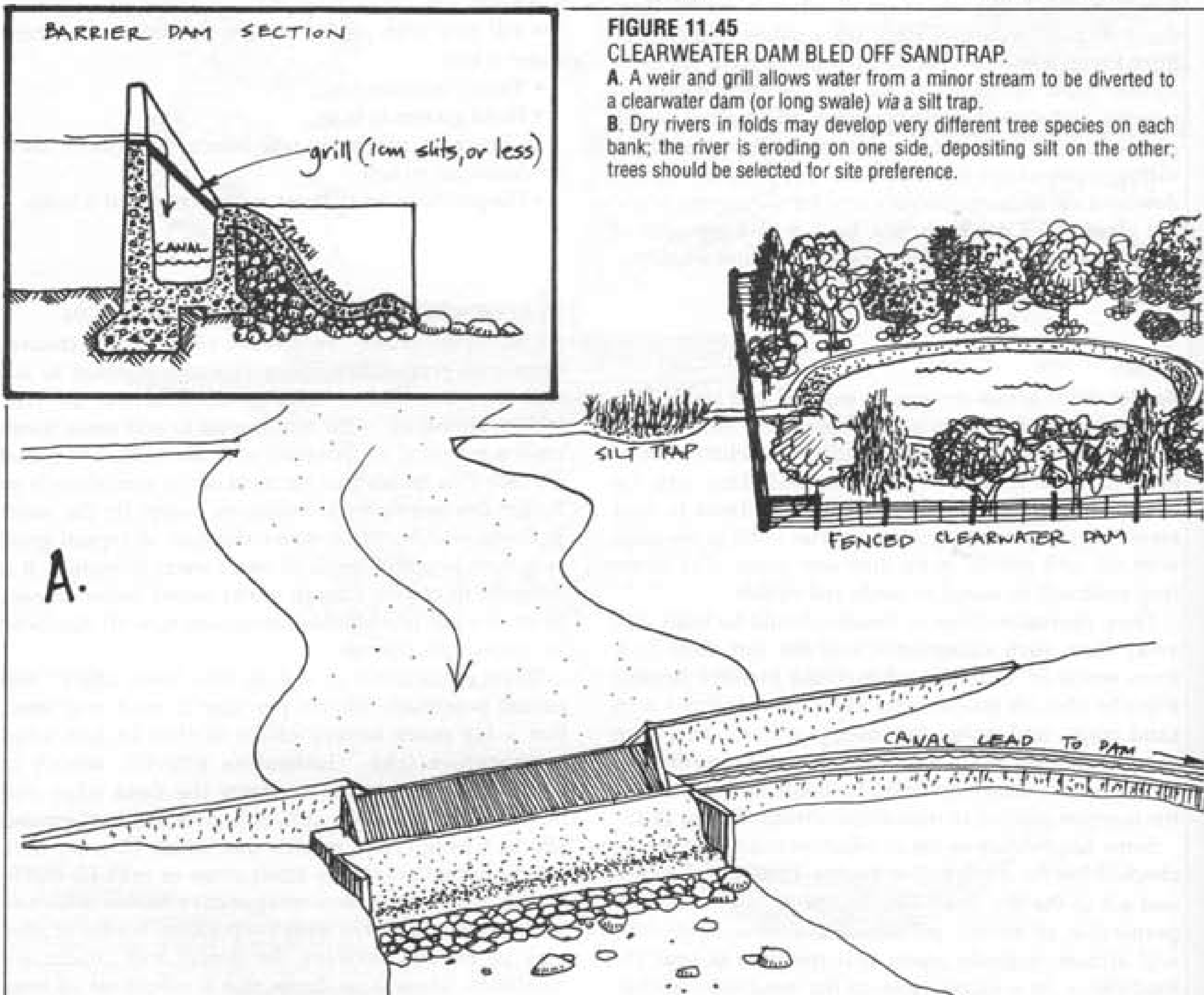


FIGURE 11.45
CLEARWEATER DAM BLED OFF SANDTRAP.
A. A weir and grill allows water from a minor stream to be diverted to a clearwater dam (or long swale) *via* a silt trap.
B. Dry rivers in folds may develop very different tree species on each bank; the river is eroding on one side, depositing silt on the other; trees should be selected for site preference.

substantial head pressure on an immersed bag. In swales, or as a series in swales, such bags would need fencing protection from large animals, but would otherwise be evaporation–free storage, preferably silvered above to reflect light, and trellis or vine–shaded to further reduce light and heat. Bags in salt water can be towed to other locations, or pipelines led across lakes to fill storage bags near villages.

There are these basic approaches to reducing evaporation in water storages in deserts:

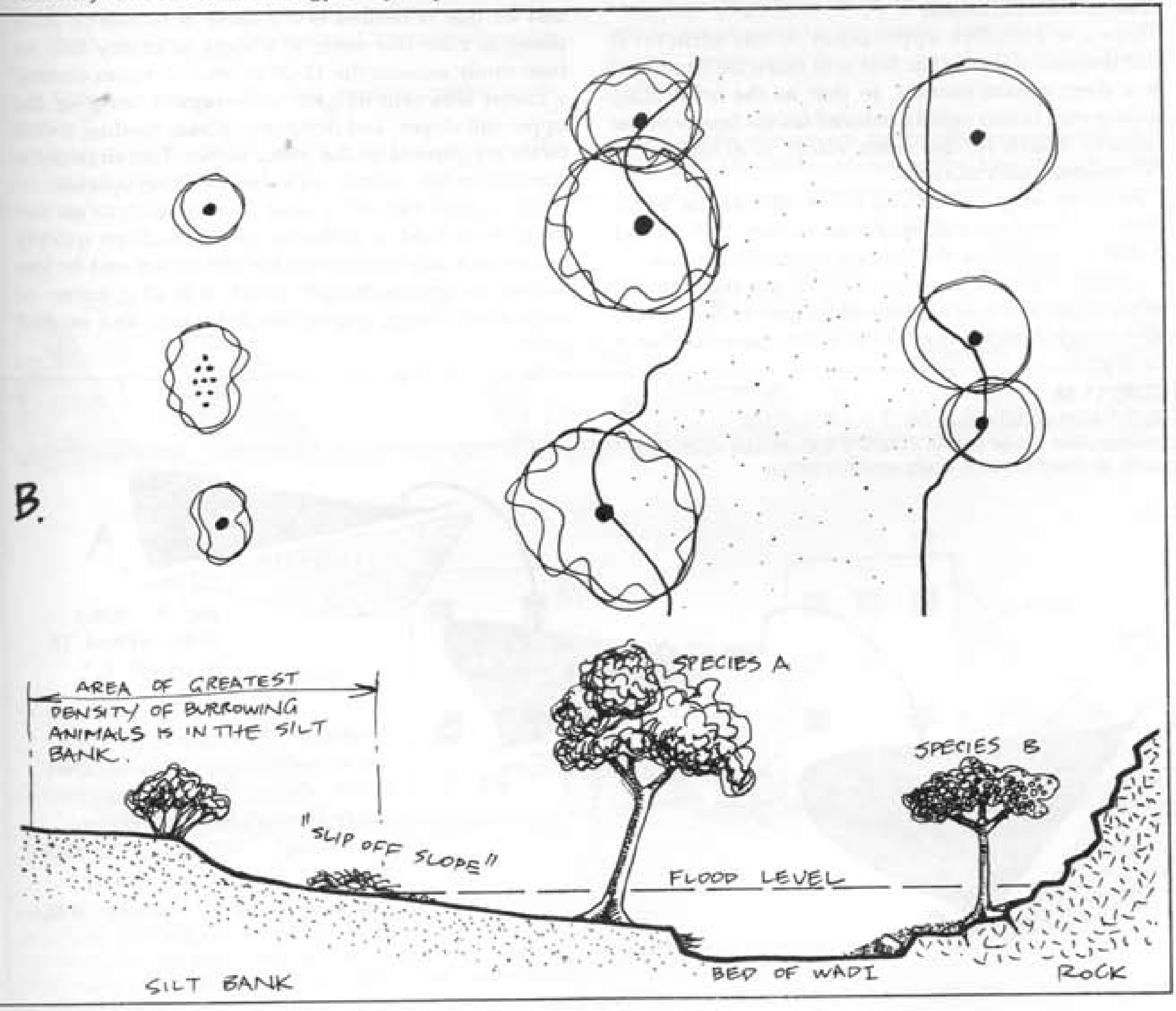
- Underground and in–earth storage;
- Surface treatment of dams; and
- Storage configurations.

Any reduction in total evaporation of water is of interest in areas where this factor may reach 180 cm in a rainfall of 30 cm. Water is an expensive resource in any situation, and more so in deserts.

Several cultures in deserts (Peru, Iran, Afganistan, Canary Islands) have avoided gross evaporation loss by conveying water to desert farms via many kilometres of underground galleries (the *quanats* of Iran) and by storing the water in clay or cement–sealed caves. This is certainly an effective strategy, only superseded in modern times by the development of extruded and leak–proof pipes and concrete tanks, by bores in headwater aquifers, and by the well and windmill systems widely used in Australia.

Water absorbed as rapidly as possible into soil is also safely out of the sun's rays, but to be efficiently stored, it is necessary to ensure that just enough water to soak the soil is admitted to swales or fields (that excess does not in fact escape to the groundwater at depth). A loose cover or mulch should be kept on the soil to prevent excess evaporation, and a crop established to use the water effectively. A 10–15 cm surface layer of loose gravel or volcanic cinder is widely used in the Canary Islands for crop and trees; coarse mulch has the same shading and insulating effect. If impermeable clays or rock lies at 2 m or so, trees can retrieve all water so stored, and desert trees penetrate to 30 m in free soils.

In view of the evaporative effect of winds, any exclusion of wind from dams greatly reduces surface loss. The exclusion can be by tree windbreak, artificial mesh windbreak, or even by building trellis or shade structure over small dams, as Australian Aborigines would do with gnammas (open rock pools). Gnammas



up to a few metres across would be completely covered with a wooden frame covered with thick spinifex, thus providing both shade and wind protection. Covered tanks are likewise protected from wind losses, although vapour pressure can cause some loss in unshaded tanks. Roofed earth tanks are still widely used in Australia.

For more extensive water systems, strategies have ranged from floating rafts of wax, to the more permanent and effective strategy used in South Africa, where hexagonal floats of white-surfaced "light" concrete (a slurry of cement, sand, fine gravel and polystyrene beads) are floated out until the entire catchment surface is covered. This is very effective where water is rare or expensive. Larger and lighter rafts could be made of sealed pipe floats and thin panels, but the concrete is durable and simple; blocks are tar-sealed below, and their specific gravity is 0.8, so that they float deep enough to resist wave effect. Corners are rounded to allow air to the water.

STRUCTURE OF DAMS

There are effective approaches to the structural effectiveness of dams. The first is to make the dam itself as a deep *conical* section, so that as the level falls, surface area is also rapidly reduced (as the square of the radius). Much of the same effect is achieved in "V"-shaped valley storages.

Secondly, deep and shaded valley sites are far better protected from sun and wind than shallow valleys, and if choice is possible a shaded east-west valley is best.

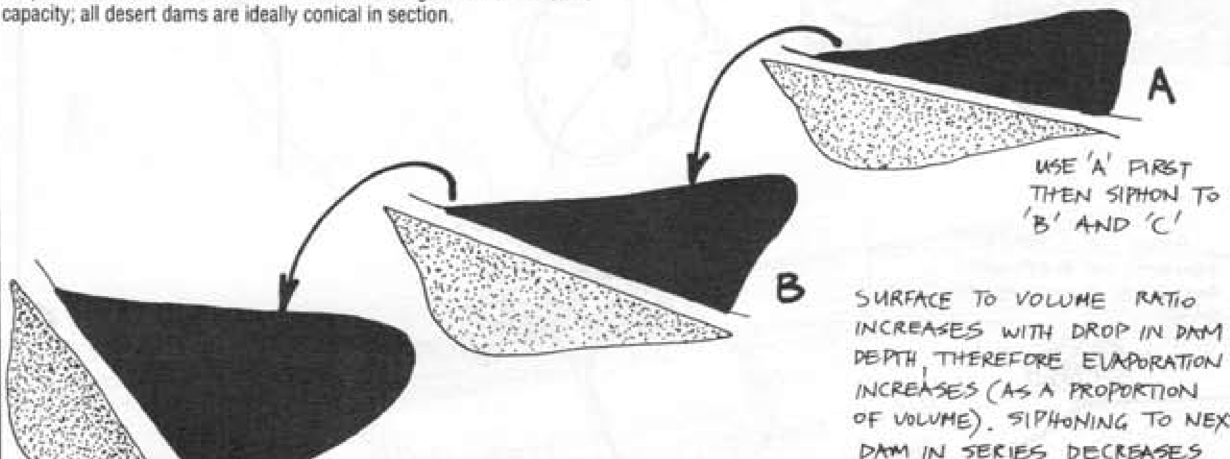
Thirdly, a simple strategy of creating a series of 3-5 storages, each able to be drained by gravity flow to the next lower dam is very effective (far more so than a single storage of the same surface area). The system needs active management so that the use sequence is from the top down; the top dam is drained into the others just when they can take any residual water. As each is emptied, evaporative surface reduces by one-third, one-fourth, one-fifth and so on. Obviously, *the shorter the series the better the result*. It is better to create two series of 3 dams rather than 1 series of 6 dams. Like much else in the desert, the scale of operations decides efficiency, and in this case smaller *is* more efficient (**Figure 11.46**).

Despite all the potential problems with salted soils and water, there are many sites in desert or dryland foothills where freshwater springs and groundwater (less than 200 ppm salt) are available, where shaded valleys can be safely dammed, and where soils are open and free-draining. Endless problems and expense are avoided if such sites are carefully identified and selected wherever local long-term food provision is of an over-riding concern.

Many ideal sites lie in the inner valleys of spaced fold mountains, where deep sands over clay hold many millions of litres of freshwater run-off from the hills, and all that is needed is a reliable windmill or solar pump to raise this water to a mesa or nearby hill. As frost rarely exceeds the 12-20 m level in warm deserts, a raised tank will irrigate "sub-tropical" crop on the upper hill slopes, and deciduous plants needing a chill factor are planted on the lower slopes. This situation is common in hill country with restricted cold uplands.

If all surplus run-off is used in wet years to set out forest trees held in nurseries, such situations quickly become not only sustainable but self-reliant and far less subject to serious drought effect. It is all a matter of careful site choice, responsible behaviour, and modest scale.

FIGURE 11.46
THREE DAMS IN SERIES REDUCE EVAPORATION.
Evaporation loss can be as little as 40% of a single dam of the same capacity; all desert dams are ideally conical in section.



11.7
THE DESERT HOUSE

Like the sub-tropical house, desert housing needs the twin qualities of summer cooling and winter (or night) warmth. Many features of desert houses resemble those of both sub-tropical and cool temperate housing. Traditional systems are often very sophisticated; the older houses of Iran, Afghanistan, and Rajasthan were all well designed for climate. Some features are:

- Cool courtyards in building interiors; narrow and tall to preserve shade.
- Evaporation strategies from water in tunnels, unglazed pots, tanks, fountains, bark mulch, and coke or hessian "wicks" for water evaporation.
- Narrow east-west steets maximised; broad north-south streets minimised.
- Use of white-painted massive walls (often of mud) as cool surfaces.
- Small windows or stone grilles; most light is indirect from the inner courtyards.
- Towers, vanes, and airscoops for ventilation systems.
- Cooking outdoors under shade trellis.
- Earth sheltered or underground housing of various types.
- Vines on walls, over roof areas, gardens, storehouses.
- Roof area creatively used for drying crops, washing clothes, pigeon lofts.

Houses can be constructed so that they assist other houses. The "colony of swallows nests" appearance of many settlements in arid areas is not a coincidence, as the strategy has independently arisen in Asia, India, the Middle East, in the Mediterranean, and in the Americas. Close-clustered dwellings, with the long axis of their streets east-west, and common or close-spaced walls ensures that neither wind or heat can easily penetrate the fabric of the settlement. If all these dwellings are sun-facing and of more than one story in height, cool air in shaded narrow "wells" is always available in courtyards and streets, and vents at roof level will draw cool air into the rooms of the dwellings. The bottom floors and flat roof areas are used for living, and the upper floors or roof areas for bedrooms.

However, where cultures are accustomed to more space and privacy, a line of bungalows or cabins on an east-west axis, and with dense strips of vegetation to the shade side can achieve much the same result, providing the site itself is correctly landscaped. Village Homes, in Davis, CA, USA, is an ideal model for such design. Thus, for this first factor we can set an ideal of:

- Dense housing, closely placed side by side along an east-west alignment. Few, if any, north-south cross streets are aligned to hot winds. Narrow streets, preferably overshaded by trees or two- to three-storey buildings.

- Multiple storeys are appropriate in restricted sites such as wadi banks, niches at the base of cliffs, and

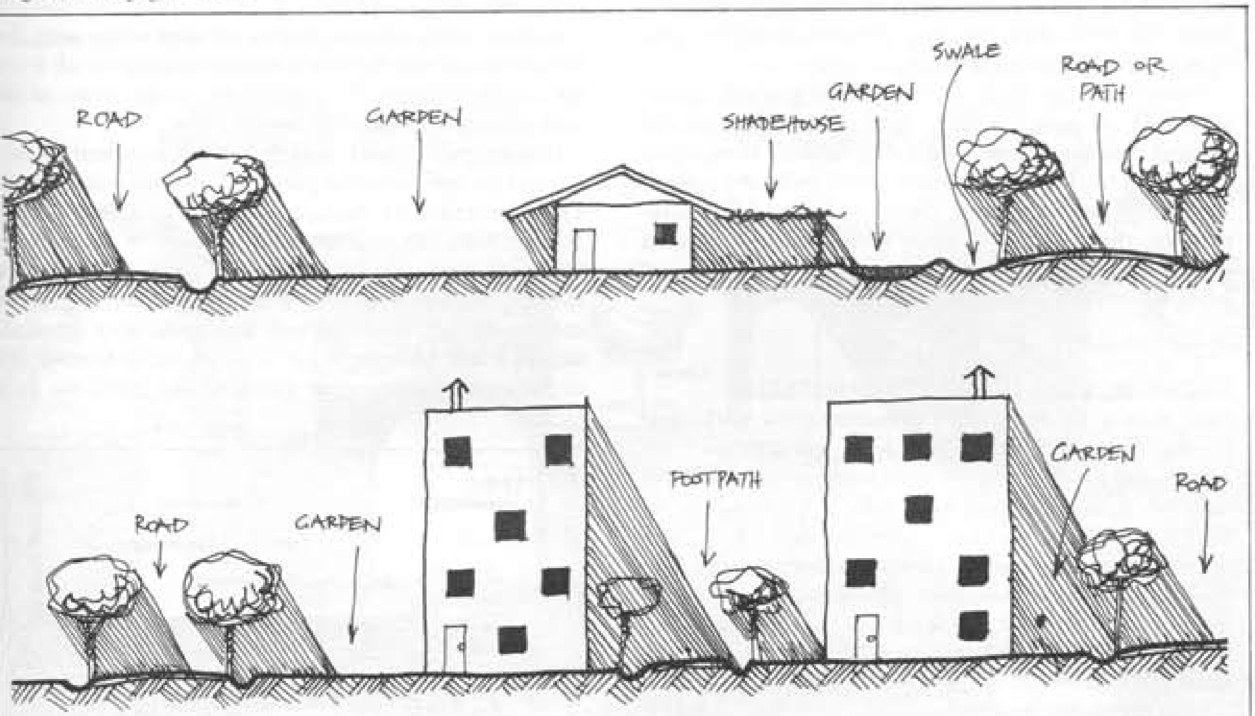


FIGURE 11.47
ISOLATED AND MULTIPLE STOREY HOUSING.
Narrow streets and courtyards can cool multi-storey buildings. Shadehouses are necessary on isolated dwellings. Tree shade reduces ground heat in all situations.

small valley sites. Single storey housing is appropriate on more open sites. but if then needs dense vegetation or trellis on the shade side (**Figure 11. 47**).

Any settlement planning broad–paved (bituminous) boulevards and parking areas will incur areas of uncontrollable local heat. Roads and car parks, or hard paving, *must be shaded* and therefore narrow. In Davis (California), at least 60% of such areas must be shaded, by law. Shading of lanes or streets by trellis and lattice is a very pleasant and practical way to create cool refuges in desert towns. The painting of roof areas or the top surfaces of lattice white reflects heat back to the air above the settlement. The white canvas–covered markets of Istanbul are a model of good design for commercial areas.

SITE CONDITIONS

No house or village site needs more careful selection than that of desert lands. Of the range and basin topography, only 15% is hill country, and of that only 5–10% is foothill or wadi site with adequate run–off. In both hot and cold desert, flat sites can be very cold at night; a thermal belt does exist, usually some 10–20 m above the peneplain, with the frost line sharply defined.

Wadis are excellent sites in very hot deserts, and narrow east–west wadis are particularly well–shaded, but in fold mountains or low foothills a run–off area or spring is needed. The main consideration is the potential for water harvest and storage on or near the house site (excluding the deep groundwaters), equable climate, and if possible a variety of aspects and soils.

Deserts are the ideal sites for underground, earth–sheltered, or cave housing. Arid areas also suit flat parapet roof areas, extensive trellis, and the integration of house, water, and a vine crop. Below ground, "dugout" houses are cool, clean, and need low maintenance; they also suit casual extension and present excellent sculptural potential.

UNDERGROUND AND EARTH–SHELTERED

Due mainly to Australia's preoccupation with opal mining, large–bore (to 80 cm) drills, vacumn earth removal, and easy drilling by machinery is now available for cave construction (at least, it is at Coober Pedy in South Australia). Even where these aids are unobtainable, there remains the wheelbarrow, pick, and shovel. In the latter case, site choice is much enhanced if the proposed dugout site is in soft rock capped with calcrete or a hard and impermeable layer at the roof level.

Mud for bricks, pise, or bulldozed earthwall shelter is usually available, and quite ordinary axes will plane soft rock walls in caves.

Vents, cisterns, toilets, cellars, fireplaces, cupboards niches, beds, and tables can be excavated in carefully planned caves. Chimneys or vents are drilled, cisterns are rendered. (Cisterns can be opened from the upper surface and deliver water at head to the lower cave.) Toilets (in Cooby Pedy) are a vertical drill–hole 20–30 m deep, sited a few feet from the door. Low–flush toilet systems can feed into them, and they are then vented to air. Or they can be dry pits with compost, down draught, and solar chimneys. In either case, they last for years, but are best occasionally pumped out for establishment of trees around the site.

Where water is sufficient, low–flush toilets are led to soakage beds where large trees rapidly transpire the water and convert nutrients. Large shallow leach–fields with thick top mulch are also officially permissible in arid Australia (**Figure 11.48**).

I think there is nothing so peaceful as a cool desert cave with a domed ceiling, the rock trimmed nicely flat, and a sense of safety and silence. For those with deep–seated ambitions, Fresnel lenses and surface mirrors, with reflector mirrors and light guides will illuminate tunnels and rooms for kilometres deep, and "camera obscurae" or lenses will throw scenes of the outer world on walls, where the outside world can be admired but the heat avoided.

Of all desert houses, those who live there prefer caves. One of the more extraordinary underground homes was cut and planted at Fresno, California, under a calcrete ceiling by a miner (M. Forestieri). His underground house covered some 2.8 ha, and included bathrooms, fishponds, and a large citrus garden, of which the only sign on the surface was the top of the citrus trees (**Figure 11.49**).

In the Canary Islands, houses are seen where only the facade stands out, the rest is hidden underground. Even the facade is shaded by grape trellis, as are many of the roof areas of houses in the region.

In both ancient and modern times, caves and underground houses were the preferred dwellings in deserts. Their practicality depends on the location having softish rock, or a softer strata below a calcrete or ferricrete "ceiling". Cave houses (**Figure 11.50**) can be totally below ground, with skylights, or more commonly built with one wall facing the open (shaded) side of a hill. Sunrooms can be built out in front of the underground rooms, or front rooms built on as a facade.

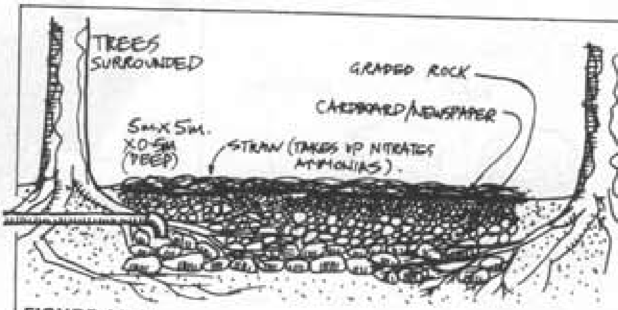


FIGURE 11.48
LARGE SHALLOW LEACH FIELDS.
Off small dams, "spillways" can be very long shallow swales; this area absorbs surplus runoff and infiltrates the water to soil.

At Coober Pedy and in the Canary Islands, decorative facades may be built at a bench-cut entry. Where occasional rains are expected, sections of the hill slope above the cave can be sealed with concrete as a roof or water run-off area for water cisterns; this also prevents water seepage entry into the cave and strengthens the strata above the rooms.

In Coober Pedy, machinery is used to prepare the site. First, a cliff face some 3–6 m high is cut into the selected hillside of soft stone, using a bulldozer. Large-bore drills (1–1.5 m in diameter) such as the "Caldweld" are used to cut corridors, rooms, and storage caves to approximate size, and to sink deep wells for toilets or water cisterns. These or smaller diameter drills cut vents, light shafts, or skylights at strategic places to light the inner rooms. Rooms are then hand-trimmed smooth with an axe, floors sealed with level concrete, and below these the essential electrical conduits and plumbing are laid before pouring the floors.

Large blowers, like vacumn pumps, are used to remove spoil as the drills cut the shafts. The newly-trimmed rooms are left to dry out for a few months before Bondcrete® or a polyvinylacetate sealer is sprayed on the stone to prevent dust. Caves built in this way are dust-free, silent, and easy to maintain.

It is *essential* to ensure good venting, particularly in volcanic sediments or rhyolite rock where radon gas may accumulate in unvented rooms. Capped surface vents or solar chimneys of metal, painted black, ensure positive venting of household heat, steam, or cooking gases. Storage areas built as furniture in surface homes are cut into walls in underground dwellings. In 1985, such houses even when sealed and tiled, cost about 50% of surface dwellings. Comfort levels are easily maintained for both cold nights and hot days.

In many Mediterrarean countries, trellised entries and bright facades satisfy the aesthetic needs of occupants, and the walls themselves are often of veined, colourful, or patterned stone. Such houses were built long before bulldozers or drills by hewing the rock and removing spoil with wheelbarrows, and miners traditionally built them as dwellings in deserts. Temperatures in such houses fluctuate about 5°C, and are fairly constant at about 25°C in the central deserts of Australia.

In North Africa, large pits (20 x 20 m) are cut into the ground, and caves built off them. These courtyard pits, with rooms off them into the soft rock, are cool and protected environments. Good gutters are needed to lead water around the pits, and the walls can be trellised, as can the top opening of the pit. Water cisterns can be cut into the floor of the pit or into the upper surface. The courtyards so formed are drained by a cave exit to a cliff face, and so cliff sites are often selected.

The ultimate refuge in hot deserts are underground, mud-walled, earth-roofed and shaded houses, well-secured against the multitudinous flies and mosquitoes of the desert, and fronting on to a shaded vine arbour, with their rear walls cut into the pediment as caves.

Caves (single entrance shelters) are widely used in deserts as livestock pens (winter, in east Turkey), grain stores, and general storage rooms. They can be built to be "hot" or "cold", as follows:

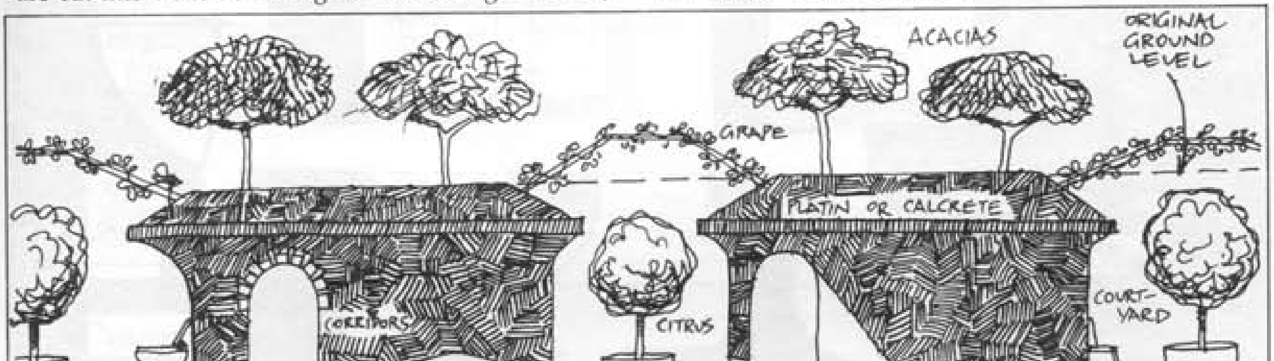


FIGURE 11.49
FORESTIERI HOUSE (Fresno, California).
Complex underground housing; only crowns of citrus trees show on surface; *caliche* forms "ceiling" in upper rooms. House can be endlessly extended, and is very comfortable in desert climate. Good venting for the removal of naturally-occuring radon gas is essential.

• HOT CAVES: A bubble of hot still air gathers in the cave during the day. Dry heat storage suits dried fruits, and mummifies wood and paper. The essential here is that the entry is overhanging to trap hot up-slope air; the cave walls are an effective heat store. Such caves may be unhealthy for living (due to lack of adequate ventilation), but make excellent grain and livestock storages in winter. The cave itself has to be built upslope from the entry in order to hold the hot air. **Figure 11.51.A**.

• COLD CAVES: These are excellent root storage areas, and also general storage areas for books, films, machine parts, and foodstuffs. The essentials are that the entry lies in a dip on a hillside, permitting cold night air to pool in the downsloping cave. A sill to the entry is essential where rains can affect drainage (**Figure 11.51.B**).

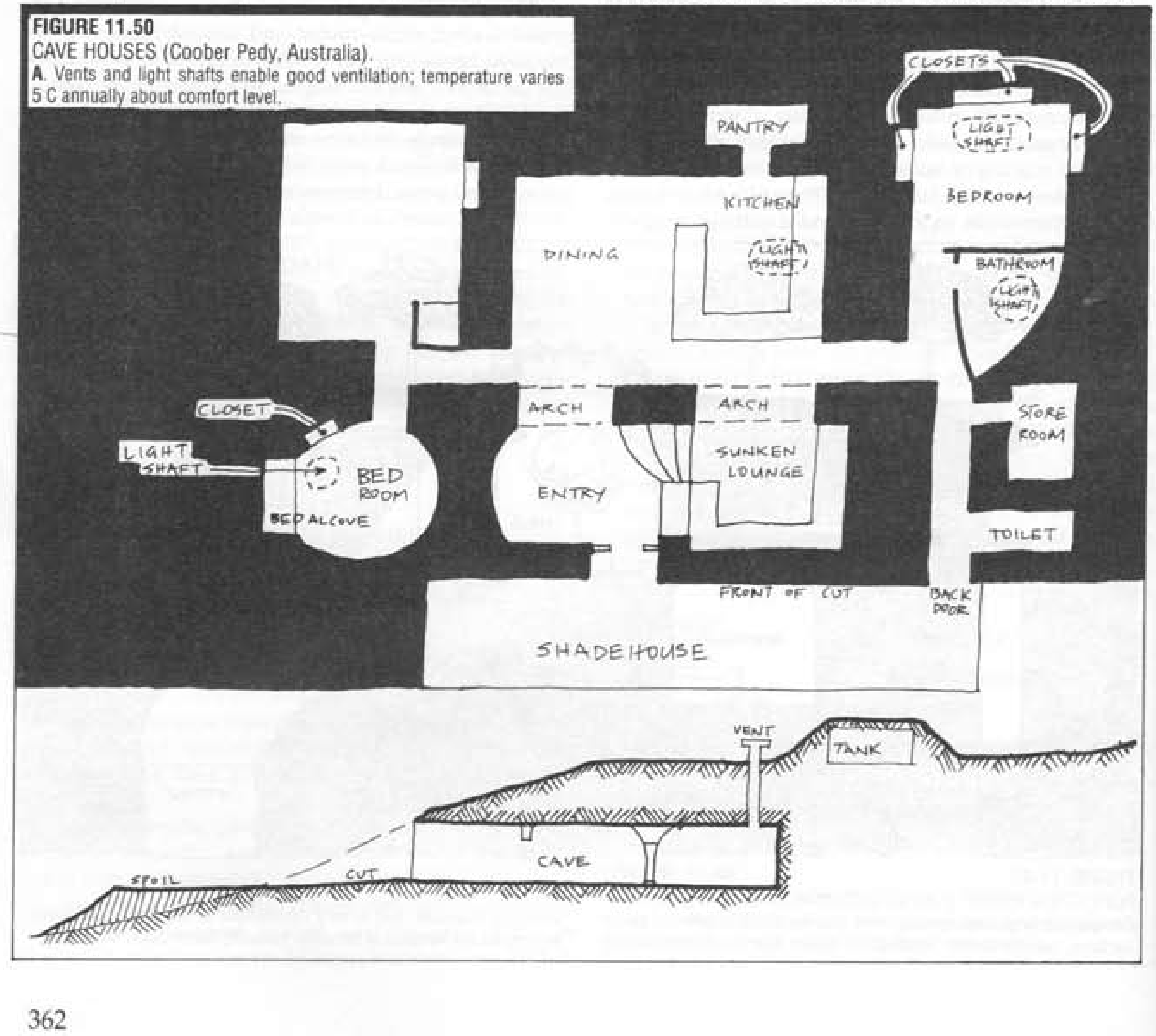
Most dwelling caves have level floors and entries, but within these complexes, both hot and cold storages can be built. Many countries have instances of ideal rock, tuff, loess, or bauxitic rock containing complexes of dwellings and storage caves. China, Iran, Turkey, Australia, North Africa, and the Canary Islands all have many examples of very successful and long-occupied dugouts of various degrees of luxury and complexity. Deep cave complexes are now illuminated using surface fresnel lenses, mirrors, and light guides of solid plastic.

EARTH-SHELTERED HOUSING

Where soils or stone will not support caves, surface housing of concrete walls and roofing, with earth-banks built up to the eaves (and if required, over the roof) effectively duplicates cave conditions, without the risk of soil collapse or water seepage. Where stable clay-fraction soils are available, a bulldozer can quickly consolidate a "turkeys nest" dam above ground, and when this is formed and roofed, it too is a cool house for deserts, allowing a variety of treatments on the inner walls, and safe from even severe surface flooding (**Figure 11.52**).

Intermediates between excavated and surface housing are found in the compact, notch-sheltered pueblo housing of the Great Basin desert (USA), and analagous sites in China and North Africa. Large

FIGURE 11.50
CAVE HOUSES (Coober Pedy, Australia).
A. Vents and light shafts enable good ventilation; temperature varies 5 C annually about comfort level.



rockshelters at the base of scarps or cliffs are "built in" with mud brick to provide cool and secure storehouses and dwellings, safe from flooding, rain, and sun. Even when abandoned, these pueblos last for hundreds of years in good condition.

SURFACE HOUSING

The desert is also suited to surface-excavated or hill-stepped houses compacted by bulldozer (**Figure 11. 53**). This beats mud brick, and may last for millenia. Thick mud walls can be built out from half-caves, or in very hard country, surface housing can be built. Surface housing is more practical where flooding may occur in thunderstorms, and where sediments are unstable or

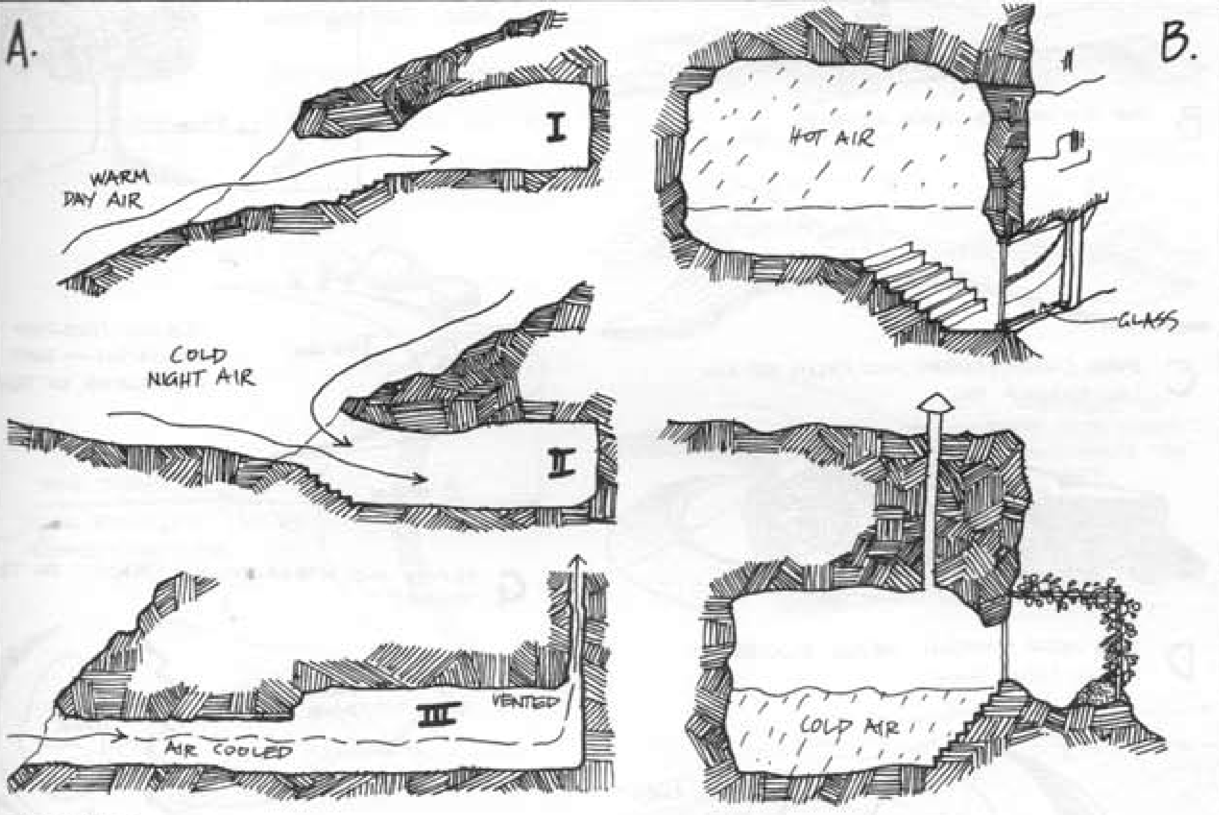


FIGURE 11.51
CAVES WITH COOL OR WARM AIR SUPPLY.
A. Cold storage caves trap night air from hollows; they need a sill to divert water (I). "Hot" caves trap uphill air by day and are used to dry-store goods (II). Most house caves are horizontal, vented (III).
B. Details of entries.

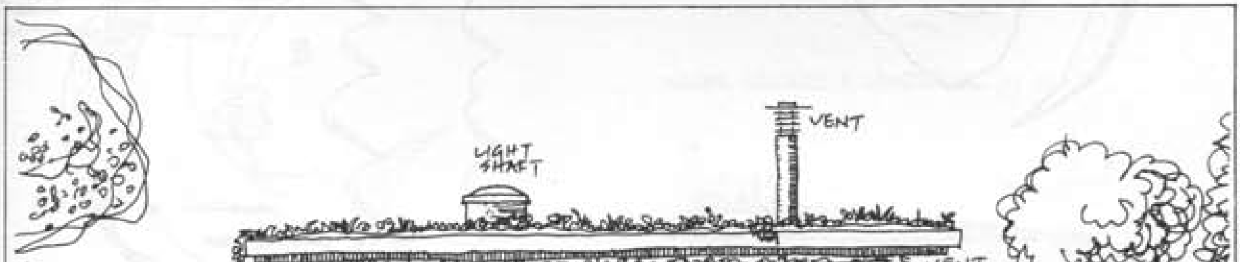
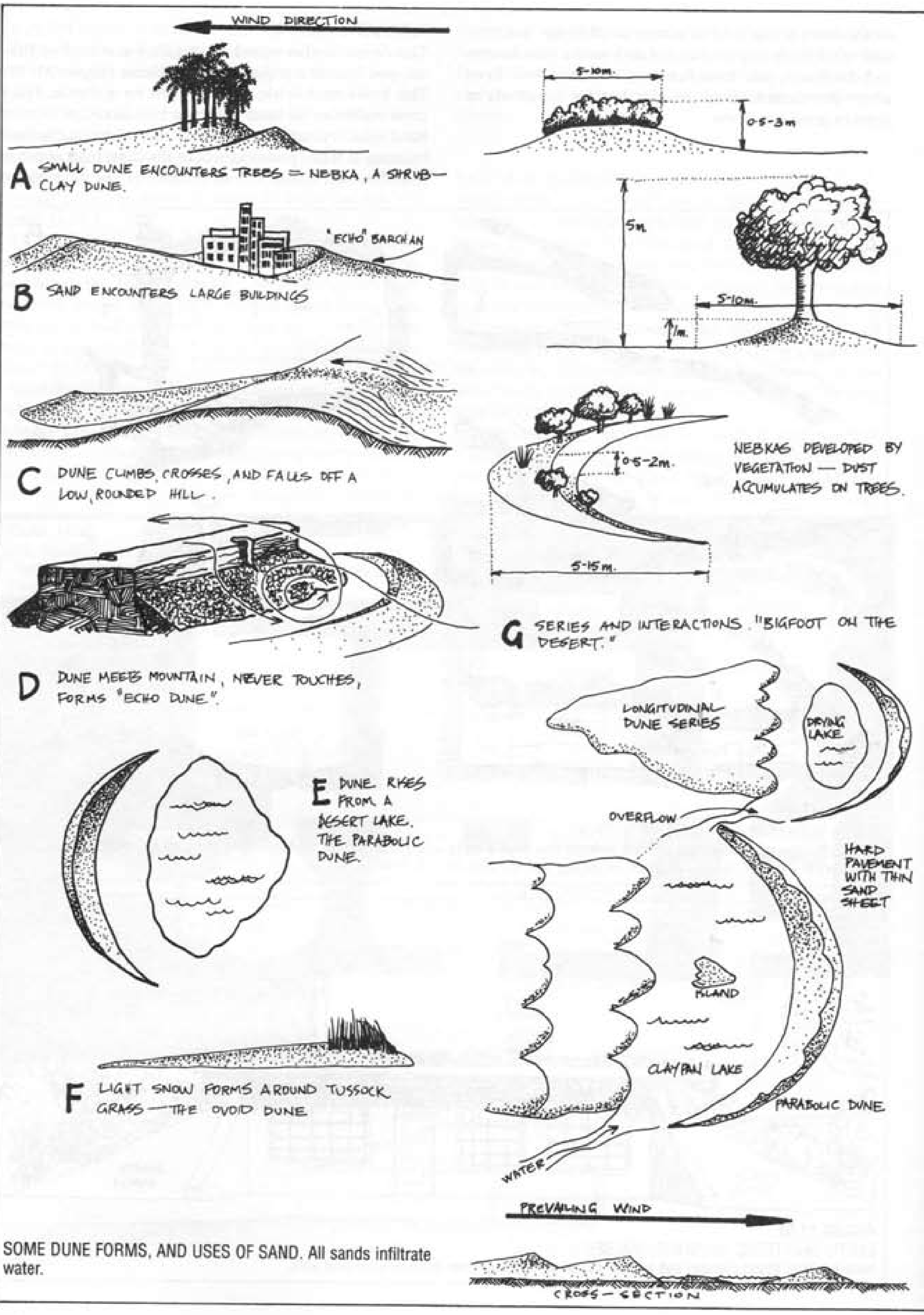
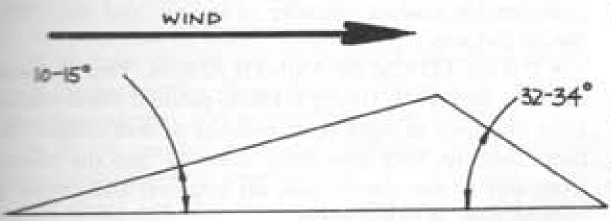


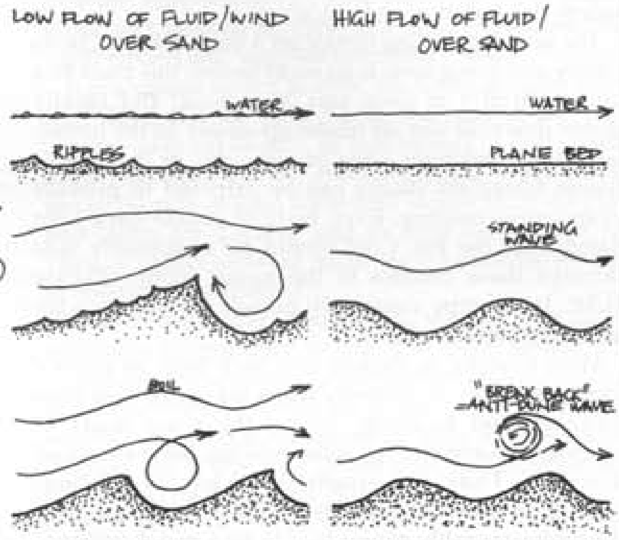
FIGURE 11.52
EARTH-SHELTERED (SURFACE) HOUSES
behave well in desert climates and are not subject to flooding; vines can shade sunward walls.

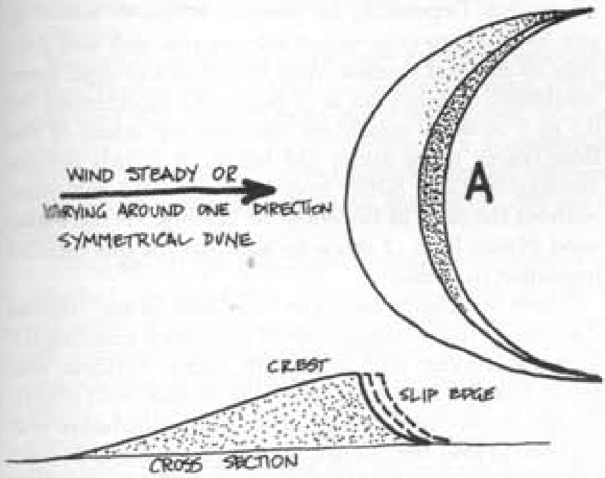


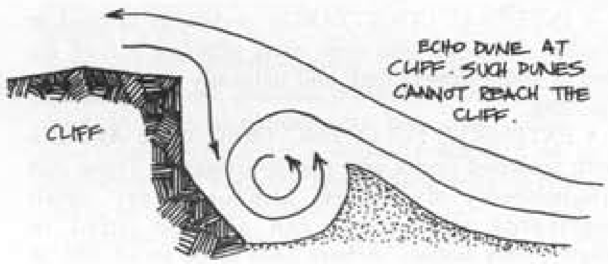
SOME DUNE FORMS, AND USES OF SAND. All sands infiltrate water.

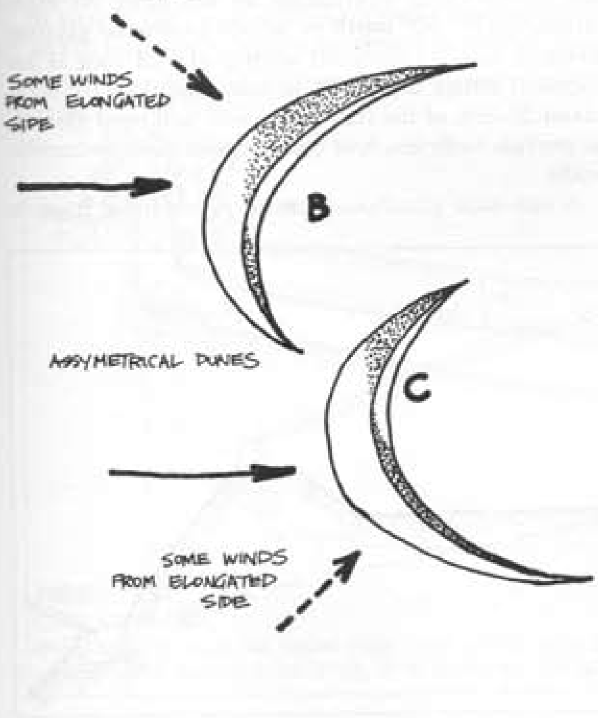


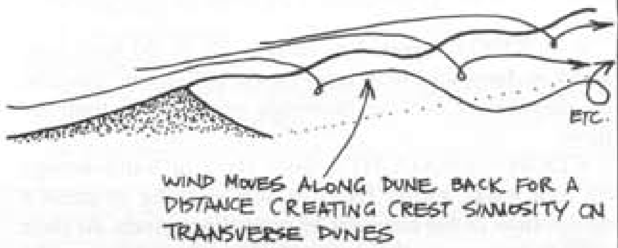
ORDER	NAME	WAVELENGTH (m)	AMPLITUDE (m)
1	DRAA	300–5,500	20–450
2	DUNES	3–600	0·1–100
3	RIPPLES	0·15–2	0·002–0·1



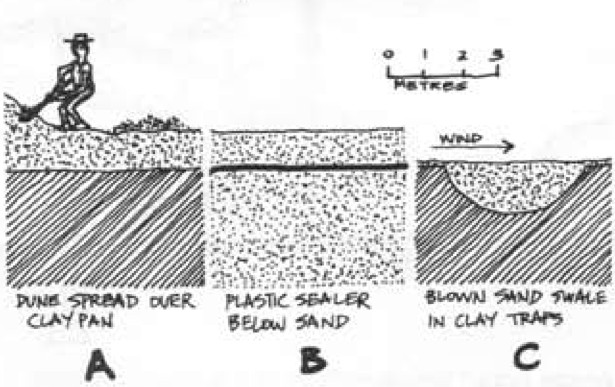








WATER STORAGE & GARDENING IN SAND.



radon-rich (granites and volcanics).

The ultimate cooling device for a surface house, or its pantry and living area, is an earth tunnel; this must be a minimum of 1 m deep and 20 m long, and ideally slopes downhill (the air intake up-slope). In the tunnel, large unglazed pots, pans of wet coke, or curtains of coarse fibreglass weave can be drip-fed to provide evaporative cooling. Even beds of coarse bark kept damp does the job. Cool humid air continually falls through these tunnels to the house rooms (**Figure 11.54**). In swampy areas, such tunnels can be mounded above the surface soil.

Most housing in deserts has been built as surface dwellings. Only a relatively restricted set of sites suits underground housing, unless these are made at considerable expense for water-sealing, excavation and drainage. Thus, the essentials of having efficient housing in desert climates is a critical design strategy. We understandably expect heat to be a major problem. There are at least these ways to provide a *cool* air source for day use:

- INTERNAL COURTYARDS: preferably latticed or shaded overhead, and even more effective if they are two or more storeys high and naturally shaded by the building.
- EXTENSIVE FULLY ENCLOSED VINE ARBORS with mulched floors and trickle-irrigated. These suit single-storey dwellings, although very small courtyards with shade can also be fitted in single-storey houses. Arbors need to be about 30% of the total floor area to provide cool air, and hanging ferns or house plants aid in cooling, as does a water tank.
- TUNNELS, opened as ditches 20 m (60 feet) long and 1 m deep, and with large pipes, half-round cuverts, or evaporative cooling materials provided in their air flow.
- DOWN-DRAUGHTS. Sails, slats, or wind-scoops on roof areas, either fixed or self-steering to force a down-flow of the constant or prevailing winds. At their outlets in rooms, these down-draught inlets can be fitted with damp hessian (burlap), coke avaporation beds, or unglazed pots full of water. These add considerable cooling capacity to the air, and humidify the air indoors.
- INDUCED CROSS-VENTILATION. This is most easily achieved by fitting a black-painted sheet-metal solar chimney to open from ceilings or roof ridges. As these heat up, they effectively draw air into the rooms from any of the above cool-air sources, and create a cool air flow in living areas.

No desert house should be planned or built without its integral trellis and garden systems, as these may not only save most or all climatic energy use (e.g. air conditioning), but provide food and shelter. The attached shadehouse, in particular, must be planned as integral to house design, and in fact as the summer living area. For this reason, the winter or indoor kitchen must open onto the shadehouse (the summer kitchen).

As well as these cooling devices, *heat* sources are needed for the frequently cold winters and cold cloudless nights. Depending on latitude, windows allowing sun to strike an edge-insulated concrete slab will provide all the heat needed. With the advent of rigid foam insulation, trenches cut at or below the foundations (to 0.5 or 1 m deep) effectively insulates the whole of the floor/earth mass under the house. It is this simple strategy that can buffer both heat and cold extremes, without the need of firewood for heating. We have also used plastic bags of straw or sawdust for this ground insulation in Nepal.

Where such slabs have not been built in the original dwelling, a thick vertical wall of mud brick standing 0.5 m inside a room, and faced with a glass window, will act as a heater long after dark (the Trombe wall effect). Finally, in very cool deserts, an attached glasshouse will act both to heat the interior in cold periods, and to vent hot air for cross-ventilation on hot days. At high latitudes (30°–60° north or south) extensive glazing needed, and a courtyard with a glazed roof is an excellent refuge from cold. In lower latitudes (0°–30°), about 20–25% of the sun-facing wall will need glazing to provide sufficient heat on to cement slabs or trombe walls.

A sun-side glasshouse has three potential uses in

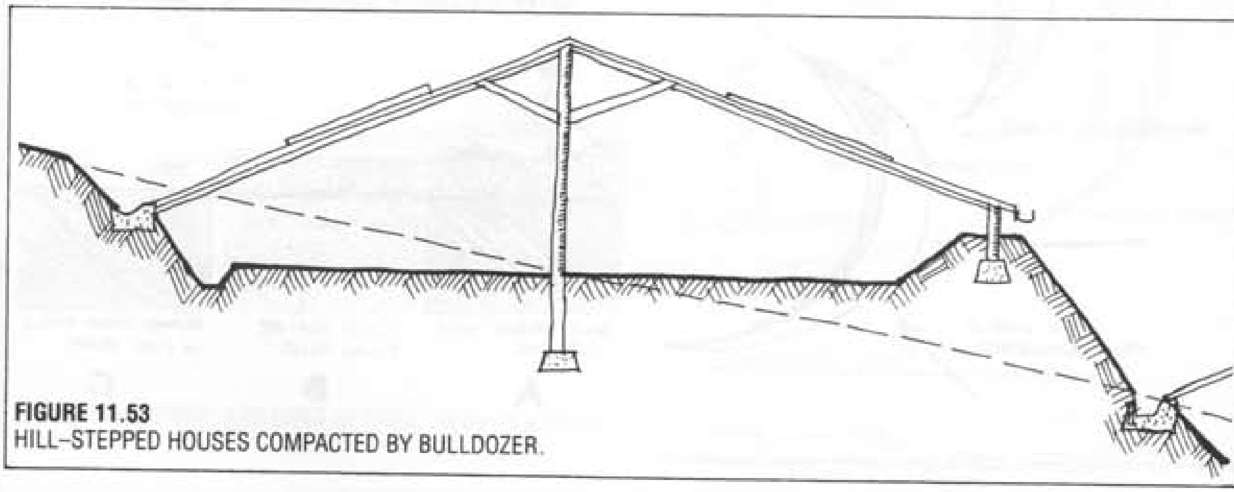


FIGURE 11.53
HILL-STEPPED HOUSES COMPACTED BY BULLDOZER.

deserts:

- To create a winter heat source.
- To draw cool air into the house during the summer.
- To start spring plants early in the year, to ripen late (autumn plants), and to grow greens in winter.
- To dry surplus fruits and vegetables in an enclosed area (unavailable to insect pests).

As these are also the basic functions of the greenhouse in cooler climates, then it is clear that such structures operate effectively over broad landscape and climatic ranges.

For both heat and cold, massive walls, edge-insulated floors, effective draught-proofing, insulated ceilings or roof areas (if necessary trellised or carpeted with thick vines), and efficient cross-ventilation are all essential strategies to moderate the extremes of daily and seasonal temperature that is typical of desert areas. White-painted exterior walls help to reflect excessive heat, and strategic shade trees, palms, vine trellis, and courtyard ponds or fountains assist in buffering heat extremes.

Houses themselves can be very compact, especially where shaded outdoor trellis areas are extensive. It is an excellent design feature to place the winter kitchen indoors, but to also have it open to a screened-in summer kitchen part-roofed under a thickly trellised area, where occupants can spend most of the day out of doors.

Quite small (in cross-section) solar chimneys or attached greenhouses on the sunward side of dwellings can create a cross-draught sufficiently strong to blow out a candle. Thus, if a fully-enclosed and totally vined shadehouse is constructed on the shade side of the house, a continuous cool and humid air cross flow results, providing the cool air can enter the living areas by a fairly direct route, and that some water is available to supply the vines with evaporative cooling (**Figure 10.17**). Commonly, air can be cooled to 10–15°C below ambient temperature by this combination of shade, vines, and induced air-flow. The same cross-flow from earth tunnels also supplies unlimited cool air.

It is a simple matter to close the house at night, or on cold days, and to retain glasshouse heat inside. Such designs save up to 80% of fuel energy, a particularly important factor for low-income groups, where energy can be 30–40% of total household expenditure. As glass and trellis are durable, and as costs amortise in 1–3 years, it makes sense to make these beneficial retrofits to uncomfortable houses.

That we see modern houses built without such aids is a witness to stupidity, waste, and poor design. The results are to be seen in deforestation and reliance on fossil fuels (with continuing pollution). More serious results are the financial strains on poor or low-income families, the ill effects of smoky fires, and illnesses due to cold and tiredness after cold nights.

Roof and Parapet Furniture

Wherever rainfall is slight, flat parapet concreted roof areas are preferred; these roof flats have a wide variety of uses for grain drying, wash-houses, pigeon lofts, and trellised-over recreation areas. In the severe winters of the Caspian area, peasants make their haystacks on the roof, in part to protect the hay from goats, but effectively providing a winter's warmth of thick insulation plus compost heat which radiates from the ceiling to the rooms below.

Features commonly built into parapet roof and trellis roof areas are:

- Pigeon lofts for eggs, squabs, manure.
- Laundry troughs and drying lines.
- Header tanks for 1–2 weeks water supply, fitted with float valves.
- Wind towers, with scoops, slats, lattice, sails, or aerofoils to catch local winds.
- Evening rest areas for outdoor passive recreation;

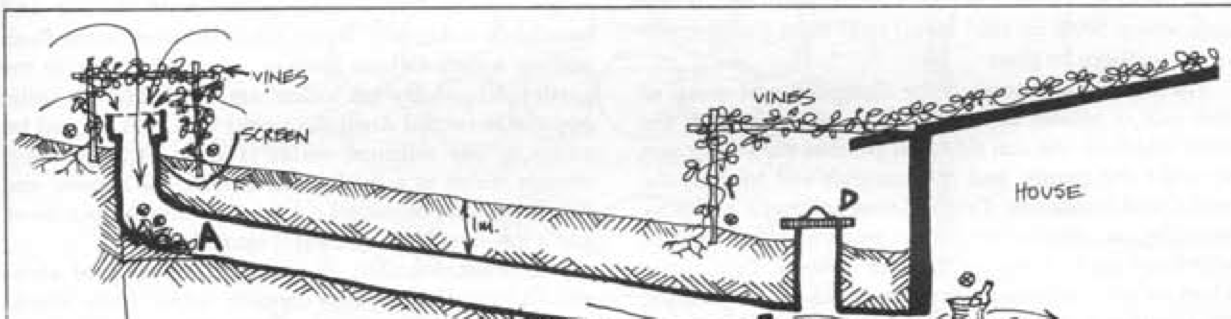


FIGURE 11.54
COOL AIR TUNNEL.
Slopes *down* to house, has shaded intake, moist coke or cinder bed, unglazed pot of water at outlet; length 20 m, depth 1 m. This tunnel provides cool humid air to dry desert houses, food storages, hospitals, etc.

hammocks.

• Grain drying flats, drying racks, bulk food stores or bins.

• Winter hay storage (in cold climates); heat or partial composting is radiated and conducted to the ceiling of rooms below.

THE ESSENTIALS OF THE DESERT HOUSE

• No west windows. West wall painted white and fully shaded, vine-screened, evergreen trees to the west.

• Cold air tunnel or cold air source as a fully enclosed, bark-mulch shadehouse.

• Positive hot air exhaust as a solar chimney or small attached glasshouse to the sun side.

• Unimpeded through-ventilation for cool air.

• Either very thick, white, fully-shaded walls (cool deserts and cool nights) or very light, screened, or matted walls (hot days and nights).

• Evaporative cooling surfaces in a through-draught; as unglazed pottery, coke mounds, ferns in bark, thick vines, or wet hessian (burlap) screens.

• Cool cellars for storages, or deep cool internal courtyards with vines and ferns.

• Ceilings insulated, thick vine mass over roof area.

PLACEMENT OF VEGETATION AROUND DRYLAND HOUSES

It is the low westerly sun that adds most heat to buildings; for that reason, *no* windows are placed in west walls where they incur direct heat gain. Permanent screens of evergreen trees, thick-leaved vines, or turf banks are placed to the west of the house so as to shade and shelter the west wall. The shade side of the house is where enclosed trellis is built. The east side can be part-shaded by deciduous trees or vines, and can have small windows. Glazing is most useful on the sun side where 100% (in cold areas) to 25% (in warm areas) of the wall can be glass.

The house itself needs to be elongated east-west, so that sun in winter can reach all room floors. It is the eave width on the sun side that permits the winter sun to enter the rooms, and the summer sun to miss the walls and windows. *External* (not internal) bamboo, wooden, or aluminium blinds prevent heat entry to windows on hot winter days in deserts. Deciduous vines on the sun side prevent too much heating during the summer months.

The correct placement of vegetation, blinds, windows, and insulation (**Figure 11.55**) means that no extra costs are incurred, but that the dwelling works efficiently. In settlements, such rules can be made part of local building legislation, and this alone will save thousands of hectares of forests in the third world.

Straw, thatch, wool, feathers, cork, woven materials, and even paper and cardboard are adequate insulators, but few of these equal thick vines over wall and roof as active cooling systems; these are affordable by any person. A desert house well screened and shaded by vegetation is an oasis indeed. I believe the emphasis in desert housing should be on developing the arbor for living, and on creating compact and reactive housing mainly for night occupancy, and in the rare case of rains.

HOME ENERGY CONSERVATION

To produce hot water in deserts is easy enough, either from:

• A solar attic with a water tank, a glass cover, and aluminium foil over thick insulation (a bulk water heater);

• A grid of plastic pipe in soot-covered sand, itself under glass; and

• A simple coil of pipe on a metal roof, so that enough warm to hot water is available.

For groups of 5–10 houses a solar pond of 4–5 m sides, and 1–2 m deep (**Figure 11.56**) will supply not only hot water, but house heating. Space heat and hot water together are about 80% of the energy needs of modern housing.

A solitary photovoltaic cell or a bank of such cells provides the little electricity needed for lights and electronics, and it remains to cook using oil, gas, or modest fires. All desert settlements should, as a matter of legislated planning, divert wastewater to firewood plantation. In a modern town such as Alice Springs or new towns, the water from washing, toilets, and sinks could provide *all* the firewood for cooking if it is carefully used in trickle irrigation systems, and stored in non-leaking and covered cisterns. Hardy desert trees on a much broader scale establish firewood reserves.

HOUSE WATER CONSERVATION

Modest water use is easily achievable if efficient shower heads are used for washing, and both shower and handbasin or laundry water is first diverted to the flush tank of toilets (where sewage is provided), or to the garden where dry pit toilets are used. The pit toilet popular in central Australia works well, and is good for years of use without water (**Figure 11.57**). To get shower water to a flush toilet cistern, the shower and handbasin can be raised a few steps above floor level, and a low-level cistern used (**Figure 7.17**).

Wherever possible, spouting from *all* roof areas should be run to covered concrete tanks. These would be a hot sales item in most of the world, but are common only in Australia (like Vegemite, electric jugs, and rotary clotheslines!) It is a rare isolated house in dryland Australia that does not boast of at least 5,000 l of tank capacity. Located on the shade side of the house, under trellis, such tanks provide cool drinking and cooking water.

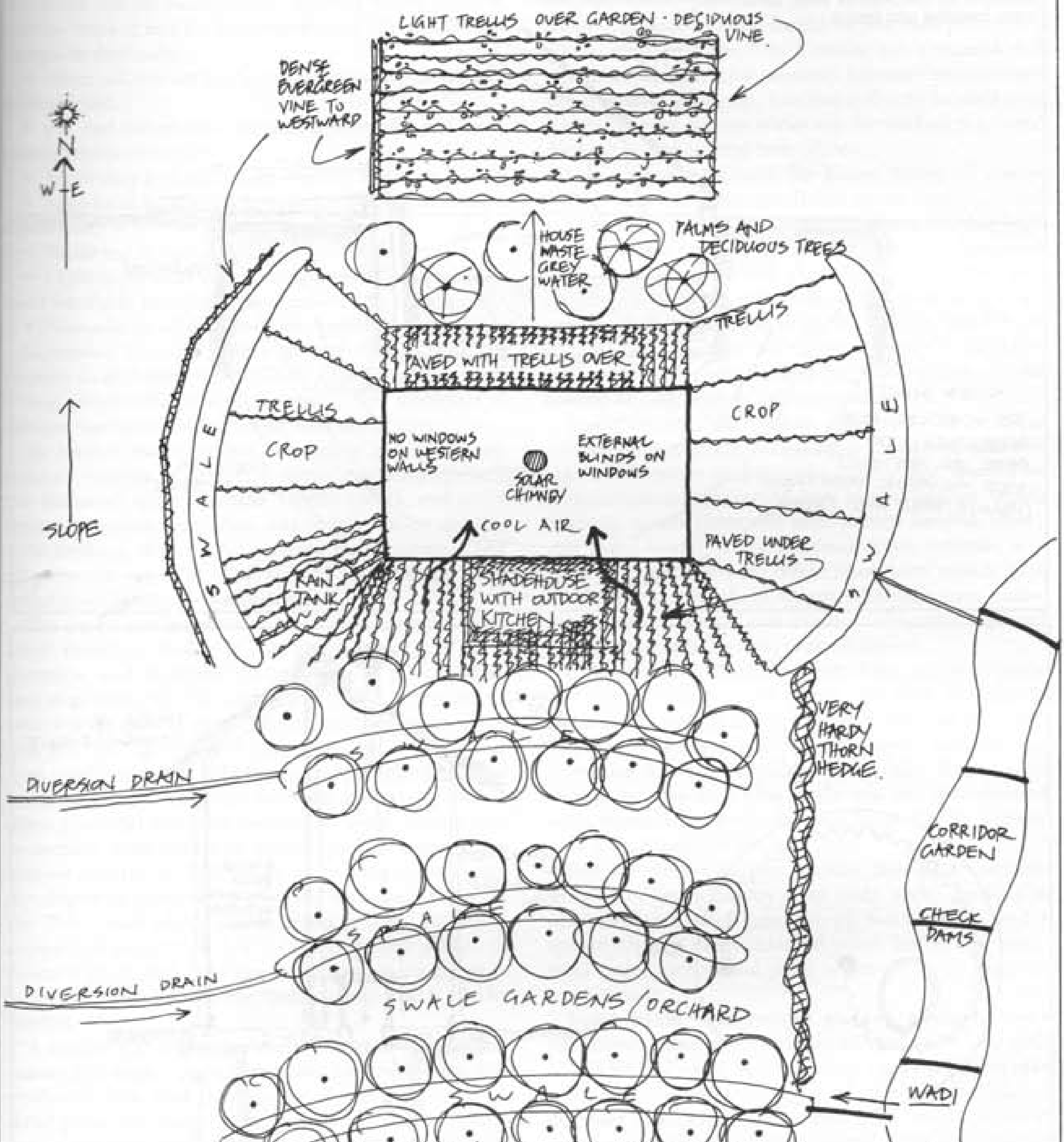
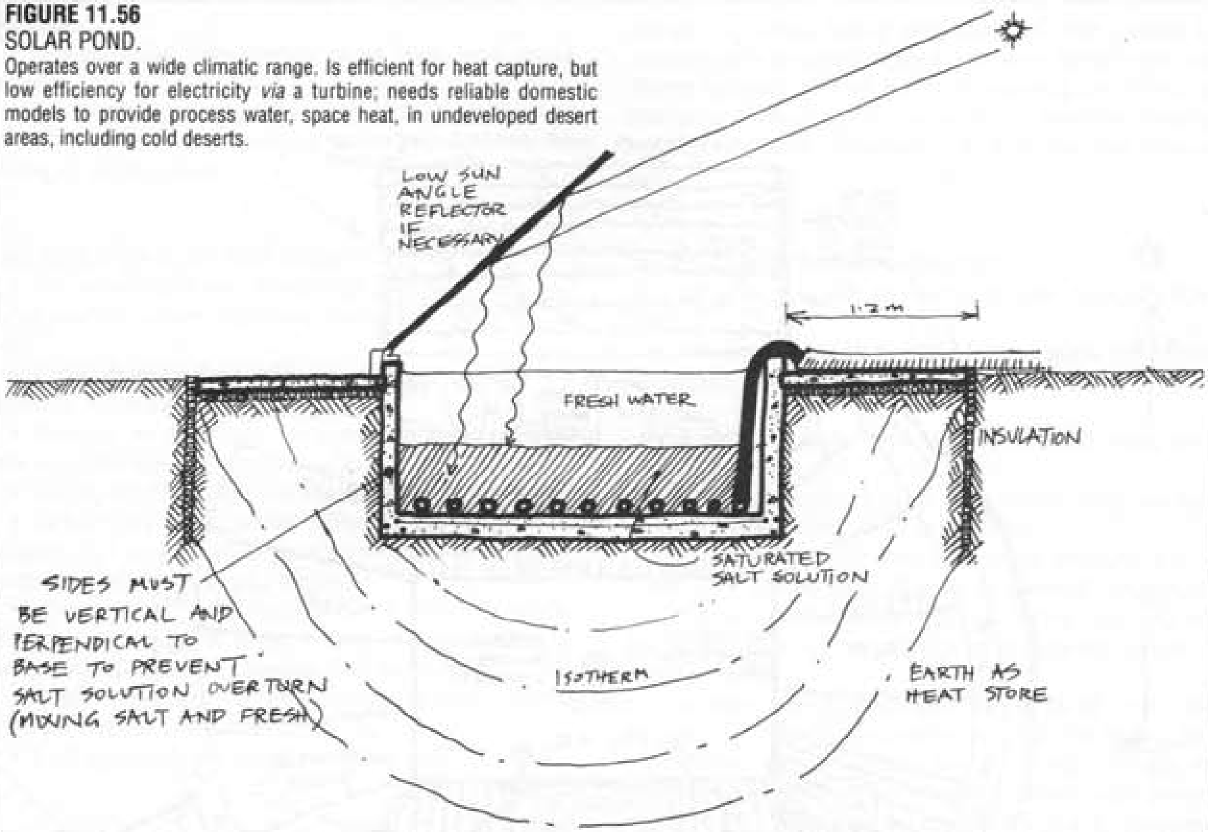


FIGURE 11.55
CORRECT PLACEMENT OF SYSTEMS AROUND THE HOUSE.

FIGURE 11.56
SOLAR POND.
Operates over a wide climatic range. Is efficient for heat capture, but low efficiency for electricity *via* a turbine; needs reliable domestic models to provide process water, space heat, in undeveloped desert areas, including cold deserts.



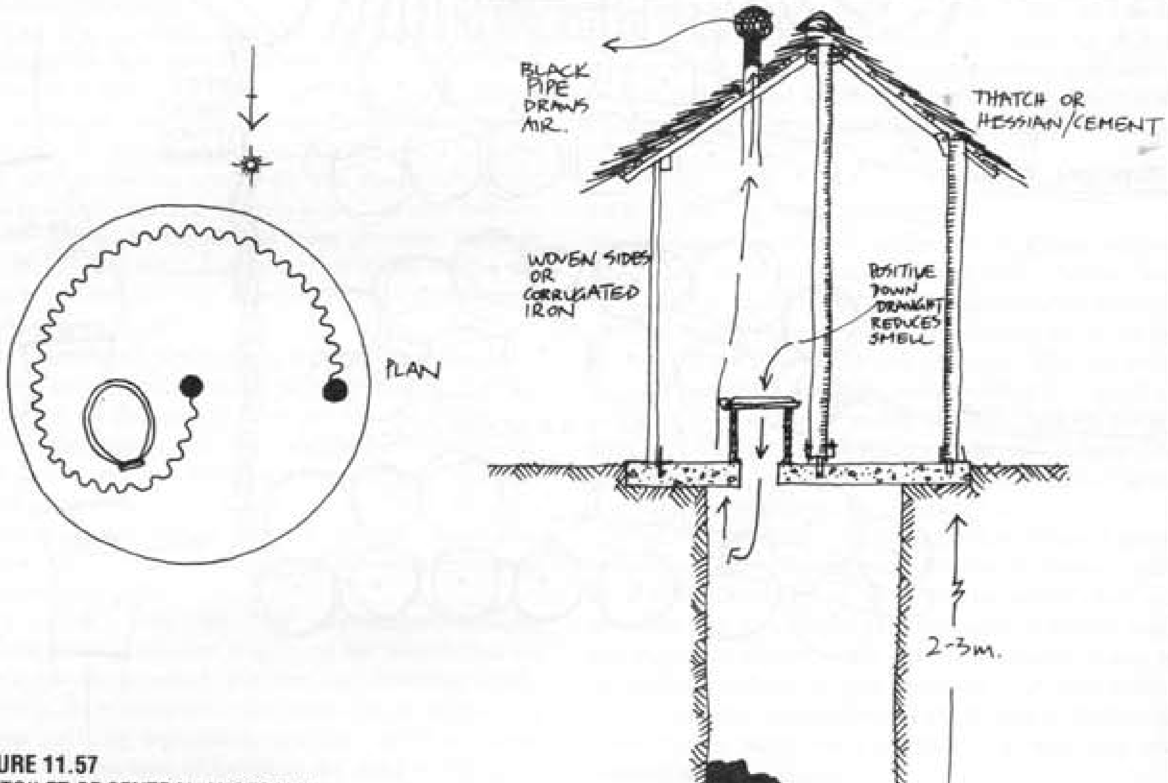


FIGURE 11.57
PIT TOILET OF CENTRAL AUSTRALIA.
External "solar chimney" (a black metal pipe) creates positive downdraght, dries faeces. Simple construction and efficiency makes these toilets popular. Note fly screen on solar chimney.

11.8

THE DESERT GARDEN

It would not be necessary to write a desert garden section were it not for these profound effects that are unique to drylands:

- Water solutes are likely to be factors higher than in humid areas.
- pH and consequent mineral deficiencies can have severe effects on health.
- There may be high nitrate levels in water and food.
- Non-local food is likely to lack vitamins, and to be expensive.
- Water use is necessarily restricted by supply.
- Light saturation of garden plants may create the need for shade to achieve good growth in gardens.
- Nomadic or wild animals are specific problems.

Moreover, because of the general low level of resources in drylands, it is unlikely that ordinary people living there will be able to afford full nutrition if gardens are not plentiful throughout settlements.

To relieve malnutrition, the home garden is our primary strategy. In deserts, gardens (not fieldcrops) are the mainstay against famine. Unlike cereals and grain legumes, garden leaf, fruit, and root products require little cooking, which saves energy in the home. They also contain essential minerals and vitamins, and can make every family food self-reliant.

The desert garden must be planned as a very serious affair. Health in deserts is very much a matter of good nutrition, and imported food often is of poor quality, and expensive. On flat and dusty plains, a few hours with a bulldozer, or many hands, can throw up a ditch and wall to 3 m or run a high barricade that discourages wild cattle and deflects winds. Solid pise and mud brick courtyard walls can be built over time; rock is often plentiful for such protective walls. Inside this protection, beds raised by stones, pise, or logs can be almost totally mulch-filled as mulch sources are developed or gathered. Individual beds can be shaded (to 75%) with shade cloth, palm fronds, or brush supported on frames 1–1.5 m high. Solid pillars of concrete block and mud brick to 2.5 m can be made to support permanent vine trellis over much of the garden.

A careful soil and water analysis is essential. We can reasonably expect phosphorus and zinc deficiency, and probably iron and manganese. Excess boron from detergents can cause plant failure, so that common soaps are best used where waste water is used on garden beds. Water must be checked for excessive nitrates and fluorine, both common dryland pollutants. All rain run-off and roof water must be carefully harvested and used to flush salts if local water exceeds 800 ppm or the garden is not free-drained.

A careful plant sequence for all beds, so that they are always self-shaded by almost constant crop is of great value. Local expertise and agricultural department advice is called for. Deep-rooting and high-yielding perennials (asparagus, globe artichoke) are standby crop, as are drought-tolerant staples such as sweet potato and most cucurbits and the melon family.

The desert garden needs an emphasis on staple trees, adapted to dry periods or able to survive on minimal water. Suggested plants would be 5–6 date palms, 4–5 olives, a doum palm, 2 or 3 citrus, 1–3 avocados, 4–5 apricots, bananas and papayas (climate permitting), and a mass of vine crop. The house should be sited near a run-off area, where water can be soaked into sand dams or swales to keep trees alive.

The garden surrounds the house, using all wastewater either as soakage fields or as underground plastic-lined swales in coarser material. Garden beds for vegetables can be carefully constructed. I have seen them built of compacted mud, filled with better soil, and mulched. Every vegetable we can grow in temperate or tropical lands will grow well in *small* beds (usually 3 x 1 m or so) flooded every 3–10 days, mulched, and part-shaded by slats, vines, or the canopy of a light-crowned leguminous tree.

Wallflowers, marigolds, gladioli, and other companion crops are beneficial to *Brassicas*, *Solanum spp.*, and onions respectively. Every bed should be planned for succession to fava beans, pea, or tepary beans in season (fava and peas in cool seasons, tepary and moth beans in hot seasons). Even potatoes will grow in deep (0.5–1 m) boxes filled with mulch, pine needles, and household scraps, although yam beans, jicama, sweet potato, and sunroot (*Helianthus tuberosa*) supply more reliable yields than potatoes.

Celery, onion, *Brassica*, carrot, beet, spinach, globe artichoke, tomato, and sweet and chili pepper do particularly well, and surplus vegetables can be dried. The desert is the home of watermelon, melons, and climbing or vine cucurbits gernerally. Every wall should be seen as a vine trellis and the roof covered with dense vine. Even flat roof areas can be shaded with a high trellis of grape.

But the desert garden should also be a corridor plantation down nearby river beds, niche gardens in shaded sites, patch gardens on leach fields, and a spread of very hardy adapted yams, bulbs, and semi-wild fruits, cactus, and palm wherever a site exists or can be made.

Sand-filled waterways always contain some moisture; these are *corridors* of moisture and soil. CORRIDOR FARMING is already a very different idea from area cropping, and we need to choose and place a complex assembly of native and introduced species to give us at least a basic food reserve, fuels and selected structural timbers.

At times, the corridors are rivers, dune series on hostile salted or stony pavement, or the floodplains of exotic rivers. These are the sites for our "semi-wild" plant and animal reserves. We can make some provision for a good rain year by broadcast sowing into areas we have already prepared for infiltration, and taking off a crop of sunflower, millet, sorghum, panicgrass, or melons. These are esentially surplus crop, for long-term storage as such, or for export out of region in trade.

MATCHING UP EARTH BED, IRRIGATION, SOIL TREATMENT, AND PLANT SPECIES

Home gardens return so much in health, cash, and just plain life interest that they deserve intensive, bed-by-bed planning, in which companion plants, seasonal successsion, bed soil treatments, and a permanent watering method are all designed. Rather than do this for every vegetable, I will deal with 3 or 4 classes of each and suggest a method to suit; people can then follow the methods (all of which are working) for other plants of like needs.

Depending on resources, beds can be raised by digging, and edged with pise (rammed damp clay-sands), bricks, logs, or stone walls. Trellis can be of metal mesh, bamboo, hardy and even crooked termite-resistant wood, cane grasses, or living leguminous trees. Deserts have supplies of clays, sands, rubble, and sometimes lime or gypsum for use in gardens.

In gardens, we can experiment with a variety of pits, circles, raised beds, "padi" beds for flooding, ridge and furrow, edge-banked raised beds, "cone and hollow", and mulch baskets or mulch boxes for some vegetables (**Figure 11.58**).

Where plastic irrigation pipes are absent or expensive, adequate substitutes can be made of unglazed pots,

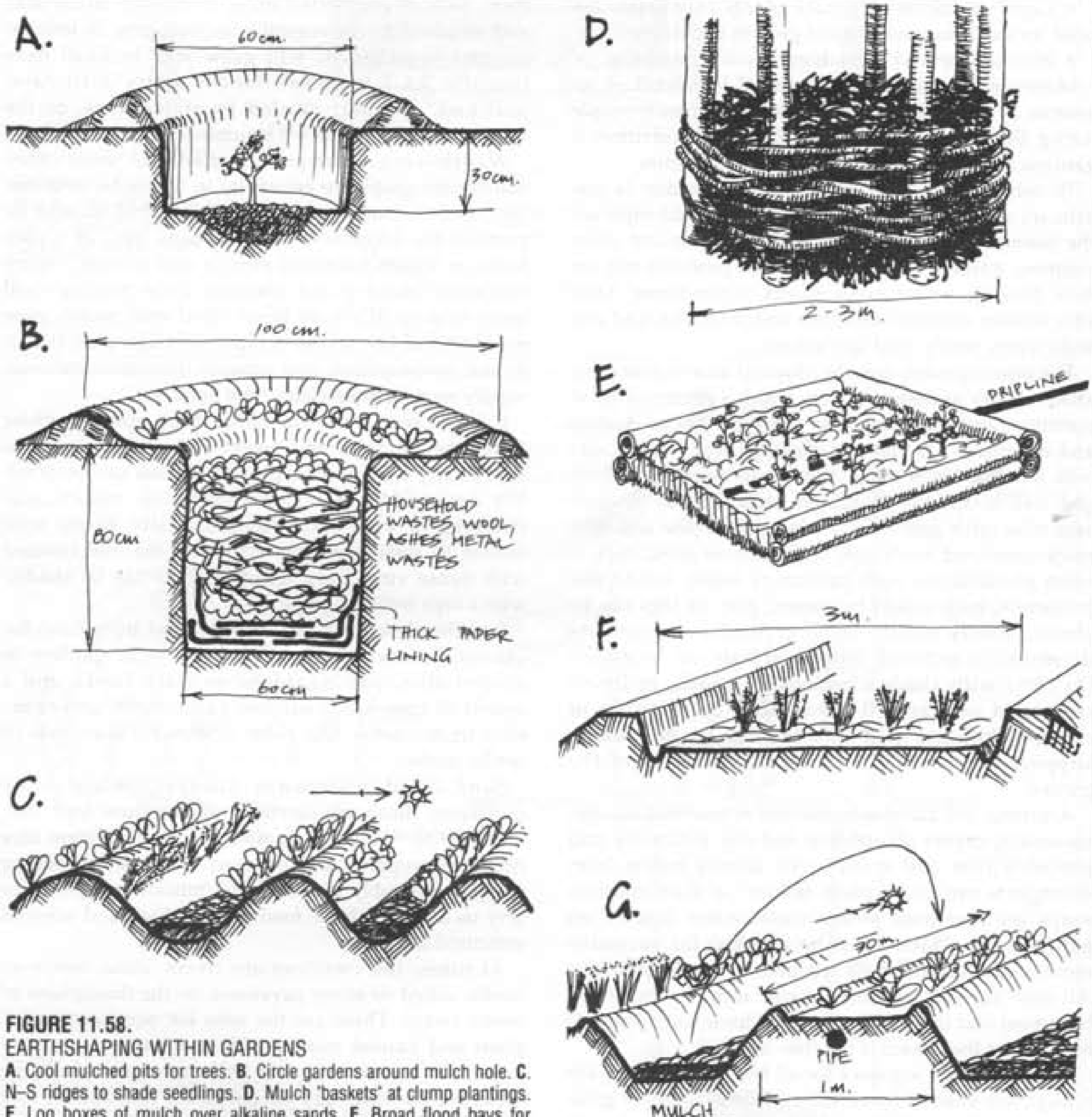


FIGURE 11.58.
EARTHSHAPING WITHIN GARDENS
A. Cool mulched pits for trees. **B**. Circle gardens around mulch hole. **C**. N–S ridges to shade seedlings. **D**. Mulch 'baskets' at clump plantings. **E**. Log boxes of mulch over alkaline sands. **F**. Broad flood bays for (e.g.) carrot crop. **G**. Top–watered raised beds for salty water supply (to 1,200 ppm).

broken pipe, gravel beds, or hand-moulded concrete channels on or below the surface, the latter covered with tiles or any flat material. Pipes of bamboo, drilled to drip water, flagons or bottles suspended and the corks perforated to leak, or simple bucket systems can be used, albeit with more labour.

The categories of things we plant are:

• ADVANCED PERENNIALS or trees in pots, e.g. herbs, shrubs, flowers, advanced tomatoes. Keep in pots under shade until rains have fallen, transplant in cool weather. Dig holes to accept full root system; soak this hole and add a small handful of fertiliser or soil improver (lime in acid areas, gypsum in alkaline clays). Turn out the pot and plant the seedling, pushing a shade branch in nearby to shade and shelter the plant.

• SEEDLINGS from trays or pits, e.g. lettuce, *Brassica*, sweet and chili peppers, chives, globe artichoke, cucurbits. Plant in cool weather, towards evening, in well-watered soils. If in compost, dibble a hole for roots. If in thick mulch, pour one-quarter of a bucket (about a litre) of good soil in a hole made in the mulch, and place a flat stone upwind. Plant in the soil hole.

• TUBERS AND BULB, e.g. potato, yam, sweet potato, flower bulbs, sunroot. Greened and if possible sprouted, tubers and tuber shoots can be pushed down into mulch, or buried and then mulched (in damp soils).

• LARGE OR FINE SEEDS. There are two possibilities:

1. Scatter seeds over a fine-tilth bed, ideally of sieved compost, then wet and press down. Sometimes, hessian (burlap) is laid above the bed before watering, and removed on day 3 or 4 after the first signs of germination are seen. This suits larger crop.

2. A lens of fine soil 4–5 cm thick is patted down over a thick (12 cm) base mulch, and some fine seeds sprinkled on this, forming patches of crop in a general mulch; this suits repetitive sowings in home gardens.

Figure 11.63 gives an idea of how each of these classes of plants are established in thick mulch in a home garden. Such instant gardens have commonly been established in a few hours. They give a satisfactory result in the first year, but as with any garden, do not form good garden soils until a few years of continous gardening have passed, when the biological content of the soil is stabilised and crumb structures in the soil have formed.

It remains to design beds and plant guilds to suit a set of vegetables. For carrots and onions, 3–6 beds (4 m long x 1 m wide) can be used, depending on family size. Another 2–3 beds should also be allotted to chives, garlic, and shallots to ensure some *Alliums* throughout the year. Keen gardeners would include beds for leeks, sand leeks, and multiplier onions.

All these beds can be built raised but dead level by levelling with a straight-edge, and either sunken below a built-up rim, or heaped and levelled off. As both onions and carrots prefer free sandy soils with moderate drainage and modest fertility (a pH of 5.5–7.5), these are beds into which old compost and dry fine organic material such as powdered grazing-animal manures can be mixed at ratio of 1:9 or 1:6 (organic material to soil). The beds are then levelled and pressed flat, seed sprinkled over it (previously mixed with sawdust or a coloured sand to show seed coverage) and the bed flooded to the rim with water not exceeding 1100 ppm salt. This then soaks in. If the beds are covered with hessian, and inspected daily for germination, a light daily flood will have good effects on germination.

As crop tops grow (burlap removed as seeds start to sprout), irrigation can be reduced to once every 2–3 days. Carrots have 3 beds allotted, planted mid-summer, and just before and after the cool season. Surplus carrots keep well when picked and layered in cool sand in pits 0.5–1 m deep; the green tops are removed to 1 cm from the crown, and they are pitted without washing or removing any roots. Onions are hung in dry airy plaits.

For carrots, a scatter of small salad radish breaks the soil crust and "thins" the crop as the radish mature in a few weeks and are removed. For onions, gladioli inhibit most pests and provide a small cash crop. For both crops, a nearby border of sunflower, *Crotalaria*, or marigold (*Tagetes*) reduce wind effects, which can devastate onions, and provide a mulch source. *Tagetes* reduces nematodes, as does *Crotalaria*, and the latter provides soil nitrogen and mulch.

An example of a SEEDLING crop are peppers or tomatoes. Although soil tolerant, both appreciate a pH of about 5.5.–6.8. Tomatoes can tolerate about twice the salt in soils of peppers, and thus peppers may need more tank water at levels of salt exceeding 1100 ppm. Both are best arranged for underground or subsurface (root level) irrigation via unglazed pottery or leaky pipes.

Both are *unsuited* to spray irrigation (as are cucurbits). Such sprays aid the spread and growth of leaf mould or mildew, and fungi. For the home garden, an efficient bed is a "keyhole" system holding 20–50 plants in 3 rows deep (1.5 m wide). Both benefit from *Tagetes* interplant and a wind shelter of sunflower, sunroot, or *Crotalaria*. A culinary accompaniament is basil.

These keyhole beds provide easy access with minimum path:bed ratio or wasted space. Both plants do well when set out as strong seedlings in soil pockets in deep mulch. **Figure 11.60.A** and **11.60.B**. For ROOT crop, broad beds, keyholes, or long rows are able. The one essential is thick coarse mulch to shield the tubers and cool the root runs while keeping pH buffered. Potato and sweet potato prefer organic dry soils (pH 5.0–6.8) achieved by compost, perhaps some sulphur, and a thick damp mulch. Subsurface water is ideal, and a few marigold interplants aid root health. A family needs 2–3 successions of each, with areas of 10 square metres or so in each bed, as they are staple crops. Thus, 20–30 square metres in garden needs to be devoted to staple food.

For all these crops, specific beds can be laid out and designed to give ideal conditions. Lorenz (1980) provides an excellent planning guide for growers for many factors to do with spacing, micronutrients, pH, and yields under good conditions.

Planning a garden repays itself quickly, and a good gardener expects to amortise establishment costs (fences, beds, seed, mulch, micronutrients) in 6–8 months, thereafter gaining a profit in health, food, and cash.

The essentials of a desert garden are:

- *Small* raised flooded beds, thickly mulched.
- Permanent hardy trees on leach fields or in swales.
- Semi-wild very hardy bulbs, tubers, and yams in selected sites.
- Every bit of waste water directed to leach fields, also surplus from roof and run-off.
- Vines, their roots in cool mulch or inside shady walls, a major feature of the garden. Every wall, open space, and roof vine-shaded.
- Mulch. Mulch. Mulch. Mulch.

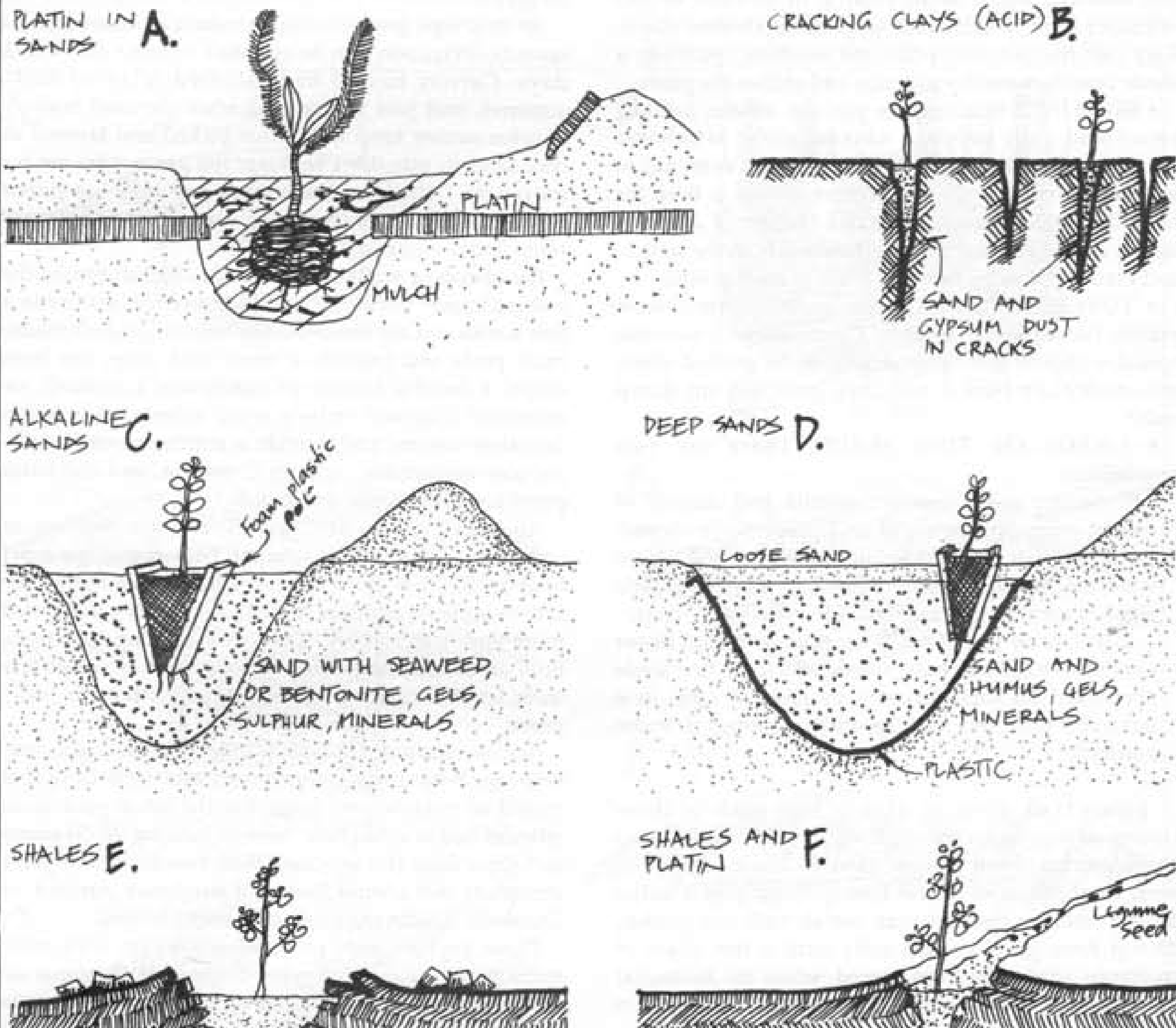


FIGURE 11.59
PLANTS IN DIFFICULT SOILS.
A. Calcrete layer cracked open, pit of humus and organic wastes allows the roots to lower damp sands. **B**. Cracking clay soils filled with sand–gypsum mix before seedlings planted. **C**. Gels mixed with trace elements, sulphur before planting in alkaline sites. **D**. Plastic liner to holes in deep sands holds minerals, nutrients, gels. **E**. Small explosive charge shatters hard shales. **F**. Ripline opens hard pans for tree lines and water infiltration.

STAPLE FOODS

A staple food is defined as one supplying 50% or more of the diet when in season. Today, some 70% of the food eaten in western societies are supplied by 8 staple crops. No European family has 20–30 basic staple foods. Few have a choice of as many as 62–100 foods in all, and a very good home garden and livestock situation would produce about 20 vegetables, 6–9 fruits, and 3–6 meats (well beyond the choice range of an average western family). Of these, 2–4 would be considered staples, depending on the culture.

The very basic question we must therefore ask is how have we improved the Australian desert yield for people? By introducing cattle and sheep, and releasing the rabbit, we have destroyed the bulk of the useful vegetation, and almost every common marsupial or desert-adapted mammal of medium size (although kangaroos and mice survive). We have destroyed the harmless way of living and the profound knowledge of thousands of integrated tribal people for an undeserved ownership by a very few, essentially disintegrated, pastoralists.

This makes no ecological, economic, genetic, informational, or social sense and it is a denial of human rights. We have replaced commonsense with a situation of downright exploitation and rapid loss. Broadscale commercial herding is, to the desert, what broadscale sugar cane cropping is to the tropical rainforest, and broadscale soybeans to floodplain forests—a disaster in every way.

People who managed desert well for 10,000–40,000 years may have known a little about it. We have suppressed this knowledge and its right to continue to exist. Those who were teachers have become fringe-dwellers. Both genetic resources and information on management have been destroyed by "the-right-to-ruin" mentality claimed by private owners and governments.

Even the plants developed by the Papago and Hopi Indians are being lost as store foods replace desert foods. And yet it is clear from desert plant lists that there is a present potential for several staple foods, and an untapped potential for developing better cultivars of many desert plants.

Several hardy seeds were stored to extend the staple over more than one season. In Nevada, Sho-shone Indians gathered, in about 6 days, a year's supply of *Pinus edulis*, and buried unripe cones for later use if needed. Rice-grass seed *(Oryzoides)* was a similar easy staple to gather and store. Thus, staples in deserts (excluding animal foods) seem to be plentiful. It is a question not so much of gardening or farming, but of placing and managing a set of hardy foods in the best situation for later gathering.

As almost every desert garden with modest water can supply 60 or more vegetable species, and as the cultivated fruits of deserts number 30 or more in common use, and as all domestic livestock (including

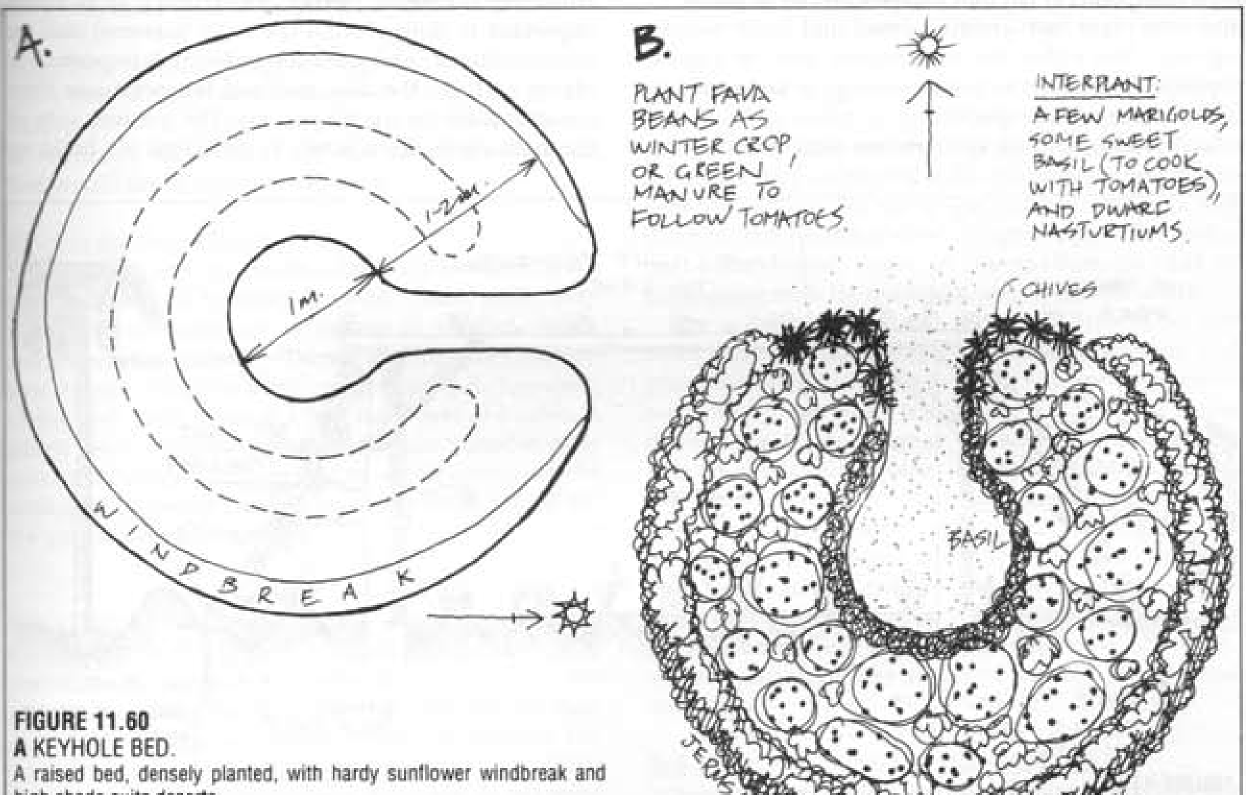


FIGURE 11.60
A KEYHOLE BED.
A raised bed, densely planted, with hardy sunflower windbreak and high shade suits deserts.
B TOMATO POLYCULTURE KEYHOLE.
Marigolds inhibit nematodes, whole area is wind-sheltered and thickly mulched.

ducks and geese) are thriving in arid areas, there is no basic problem for nutrition. Yet adequate food and good nutrition are denied many desert peoples because of the lack of basic seed and plant resources, and the denudation of the total environment by livestock.

For designers, small intensive trial systems within and around settlements are the essential precursors to wider Zone 2 and 3 trials along favourable corridors of better soils and water. The selection of existing plants, and the further addition of new species for the area, greatly assist this "nucleus of small successes" that demonstrates how larger or more extensive systems can also develop, using fewer but well-tested species.

It is always essential to build-in humus and mulch production into crops, and species used for this purpose can range from such edible plants such as *Dolichos*, edible lupin, *Leucaena*, or edible-seeded *Acacias*, to shelter, edge, weed barrier, and hedgerow species such as *Echium fastuosum*, *Acacia*, *Pennisetum*, comfrey, lemongrass, and Vetiver grass. Many trees such as *Casuarina*, some figs, *Acacia victoriae*, *Pongamia* and clump species such as bamboo also provide shelter and leaf mulch, while hardy ground covers suppress grasses and cool the roots of vines and young trees. Good "soft" ground covers outside Zone 1 are vetches, nasturtium, a variety of runner legumes, comfrey, annual lupins, and daikon radish.

The spacing of fruit trees in Zones 1 and 2 can be as usual; it is, however, essential to provide *high shade* from interplants of tall thin foliage legumes or palms, to also interplant fast-growing small and large woody legumes that either die out (pigeon pea) or can be coppiced (tagasaste) or felled or ring-barked to rot to humus (many *Acacia* species).

Such well-planned systems are very productive, drought resistant, cool, and eventually humus-rich. They demonstrate how quickly a barren or hard soil area can be brought into production as a result of intensive biomass production and wastewater use. Thus, the role of teachers and designers is to help plan and place such systems as trials in villages, to locate and provide seeds and propagules of new species, to teach the benefits of soil humus and rainwater harvest, and to stress food preparation and good nutrition.

VINES

Vines have a key role to play in desert gardens. Correctly spaced and pruned they provide both a productive crop and shade cover to mulched and watered gardens. They are also a key element in moderating climate in designed houses, or in retrofitting uncomfortably hot homes. These basic uses can all be applied in the domestic situation. There are special vines for broadscale work, and for selected niches in the desert property. We can deal with each in turn.

Vine Over Garden

Horizontal trellis bars at 1–2 m spacing and furnished with grape vines can throw a shade system over the greater part of the vegetable garden, relieving light saturation. The sides of this trellis can also be more completely closed with herbaceous vines (beans, climbing tomatoes, yams, cucurbits). It is more important to defend from the early (eastern) sun, as dew, distillation, and guttation moisture is important to plants early in the day, and soil temperatures then remain cooler for longer periods. The western side of the trellis needs fleshy vines, as great heat can build up

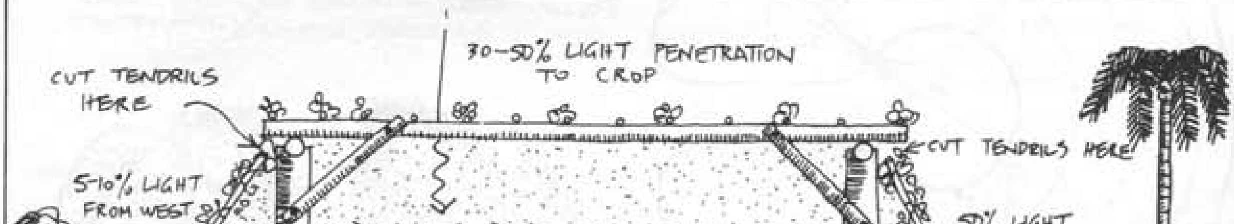


FIGURE 11.61
PLAN OF VINES OVER GARDEN.
50% or more shade helps gardens in hot clear deserts; side trellis is spaced to shut out most of the westerly sun; palms can serve as shade providers; mulch is of great benefit in all deserts.

on the western aspect late in the afternoon. A vine such as *Mikania* (mile-a-minute) is ideal. Only the shady aspect of trellis needs to be left quite open, while the sun side can be of wide-spaced pole crop. A plan is as in **Figure 11.61**.

Vine as a House Retrofit

Considerable comfort can be brought to over-hot homes by attaching trellis. The best results are achieved by:

- Standing dense evergreen vine crop out from west walls (*Mikania, Dolichos, Pelargonium*), and a vine awning above and out from any existing west windows.
- Growing vines (winter deciduous or summer herbaceous) in a screen fixed out from the eastern sun walls. These are well placed at the edge of a verandah if such exists. Washing down the verandah and spraying the vines with water rapidly cools the shaded verandah area.
- Building extensive closed trellis over the rear door, on the shade side to provide a cool air source, preferably with a thick bark mulch below the vine and fine sprays to damp it down. In this case, roof vents via the indoor ceiling or a small sunside glass-house are necessary to draw in the cool air of the trellis.
- Running a perennial non-invasive vine (*Mikania, Pyrostegia*) completely across the roof.
- Placing a water tank under the vine crop to keep the garden air cool, and to cool the water.

Vines as Mulch and Forage Sources

Vines can be vigorous producers of foliage for garden mulch and for feeding small domestic livestock. Well-chosen, shade vines can also provide some stick fuel woods for efficient cook-stoves.

Vines in the Desert Itself

Several vine crops are desert-adapted; if we include the gourds and yam legumes (ground vines), some very basic reserve foods can be set out in shaded, moist, wastewater, or soakage situations. Some vines survive dry, harsh, stony, or dune conditions. All, however, thrive and yield better if a few cubic feet of humus is pitted below the plant when it is set out. Valuable vines grown in large containers can await rains, or the soakage from water harvesting, before being placed out for permanent field growth.

FENCING

Over much of the world's drylands, the great impediment to home garden production of food is the presence of wild, feral, and domestic browsing animals. It is much cheaper to fence out these devastating and ever-hungry animals from settlements and gardens than it is to airlift emergency food aid to starving people, or to withstand the social costs of poverty and famine.

Fencing is thus a primary requisite for intensive food production in deserts. Fenced corridors or "stock routes" can permit milk and draft animals to enter some restricted areas of settlements, but it needs sound fences (preferably electrified) to exclude goats, camels, cattle, donkeys, and sheep from home gardens.

Within fenced areas, sometimes surprising natural regeneration of trees can occur, and hardy food plants can be set out in unirrigated areas if fencing is provided. These form a firewood, mulch, and medicinal resource for hard times. Poultry, domestic rabbits, bees, guinea pigs, and pigeons are all relatively harmless livestock for dryland homes.

Where there is no money available for post-and-wire fencing, more laborious alternatives are used, ranging from ditch and bank systems, either rock-faced or thorn-crowned, to woven or living fences of plant materials (reeds in the Caspian area, cactus in Mexico, *Euphorbia antiquorum* in India, *Euphorbia tirucalli* and *Lycium ferocissimum* in Africa and now parts of Australia). Combinations of stone walls, rock, thorny shrubs, and steel pickets or wires are frequently seen. In affluent societies burnt brick walls, and in Afghanistan and Iran unburnt mud brick walls, are erected around large gardens; even within urban areas of the third world, domestic animals range and destroy vegetation. Where hunting will support dogs, large domestic dogs will defend a house area (at the cost of feeding the dog). It is a matter of adapting to local materials, labour costs, and customs.

SOILS

In drylands, any soil humus can rapidly decompose (in dry-cracked soils) to nitrates with heat and water, giving a sometimes lethal flush of nitrate to new seedlings. Dry cultivated soils exacerbates this effect. Mulches or litter on top of the soil prevents both soil cracking and the lethal effect of rapid temperature gains that cook feeder roots at the surface, so that in subsequent rains there are less roots to absorb water.

Fire is destructive of this protective litter. After fire and cultivation, most of the soil nitrogen, sulphur, and phosphorus is lost, and even a cool fire loses plant nutrients to soil water and leaching. When we know more of the effects of fire in drylands, it is my opinion that we will use any other method (slashing, rolling, even light grazing) to reduce fire litter to soil mulch. It now seems probable that Aboriginal burning has not only gravely depleted soil nutrients, but caused a breakdown in soil structure, and perhaps has been in great part responsible for the saltpans that preceded agriculture. However, agriculture itself is a monstrously effective way to speed up this process and intensify it.

Soil Treatments in Dryland Home Gardens

Where free-draining or non-wetting sand is the problem, bentonite (a volcanic fine clay which swells up and holds water) is a great help in flood-irrigated beds. Conversely, where clay is causing problems with water penetration, the addition of gypsum enables water to penetrate further into the clay particles. Where salted soils or salty waters are a problem, the garden beds must be mounded up or raised, when the salt can wash down into the paths and low places.

Water use is efficient only if all the water soaks in quickly, and watering is stopped once the soil is saturated. Mulch greatly helps this process of fast soakage. Whatever is true of home gardens is also true of swales, and soil treatments can be the same for swales. Ripping swales helps, as do soil additives such as bentonite and gypsum. Where swales are used as tracks, gravel mulch is appropriate; coarse sand (raked to keep swales weed-free) also helps.

Swales are better made about 2–4 m (6–12 feet) wide, so that trees grown along them can overshade the swale base and so help prevent evaporation. As swales develop, salt is carried down to groundwater level. Every desert settlement of 5 cm rainfall or less can direct all road and roof run-off and tank overflow into swales. Domestic water from all sources can also be absorbed into swales, producing fruit, flowers, and vegetables for the house and village, or fuel products for society.

De-salting Soils in Gardens

The Saharawi people of North Africa, as refugees in Algeria, have developed two methods of soil treatment under irrigation that leaches salt. Both methods involve heroic or total soil rehabilitation (*International Agricultural Development* Jan–Feb., 1987).

Method 1: (where shingle or pebbles are available): Salt soil is removed to 1–2 m deep, a layer of shingle laid down, and non-salted soil carted in. **Figure 11.62.A**

Method 2:

Where no such stones are available, topsoil is removed (if clayey) to 20 cm, salt-free sand is brought in, and deep canals are cut to drain off surplus salt with the irrigation water. **Figure 11.62.B.**

DESERT MULCHES

Organic matter is as invaluable in deserts as it is elsewhere. Sources are:

- The detritus brought down in flood, which can be arrested on strong mulch-trap fences (**Figure 4.33**);
- Tumbleweeds and wisps of plants blown by wind, which will settle in pits, swales, or are trapped on fences;
- Grown mulch in our gardens and orchards;
- Plants such as *Casuarina*, bamboo, tamarisk, comfrey, some species of *Acacia*, forage grasses and legumes can be planted *for* their mulch value or nitrogenous soil fixation in specific situations. Some desert vines also provide good mulch from trimmings, as do hedge species;
- Household and storage wastes; and
- Grazers on range (if regularly penned) for mulch-manure resources.

Categories of mulches are:

- DOMESTIC old skins, blankets, cotton or wool clothes, cardboard boxes, newspapers, hardboard and thin planks. All of these, soaked, can be used to line sandy pits, or tiled over the ground in raised beds before mulch is added.

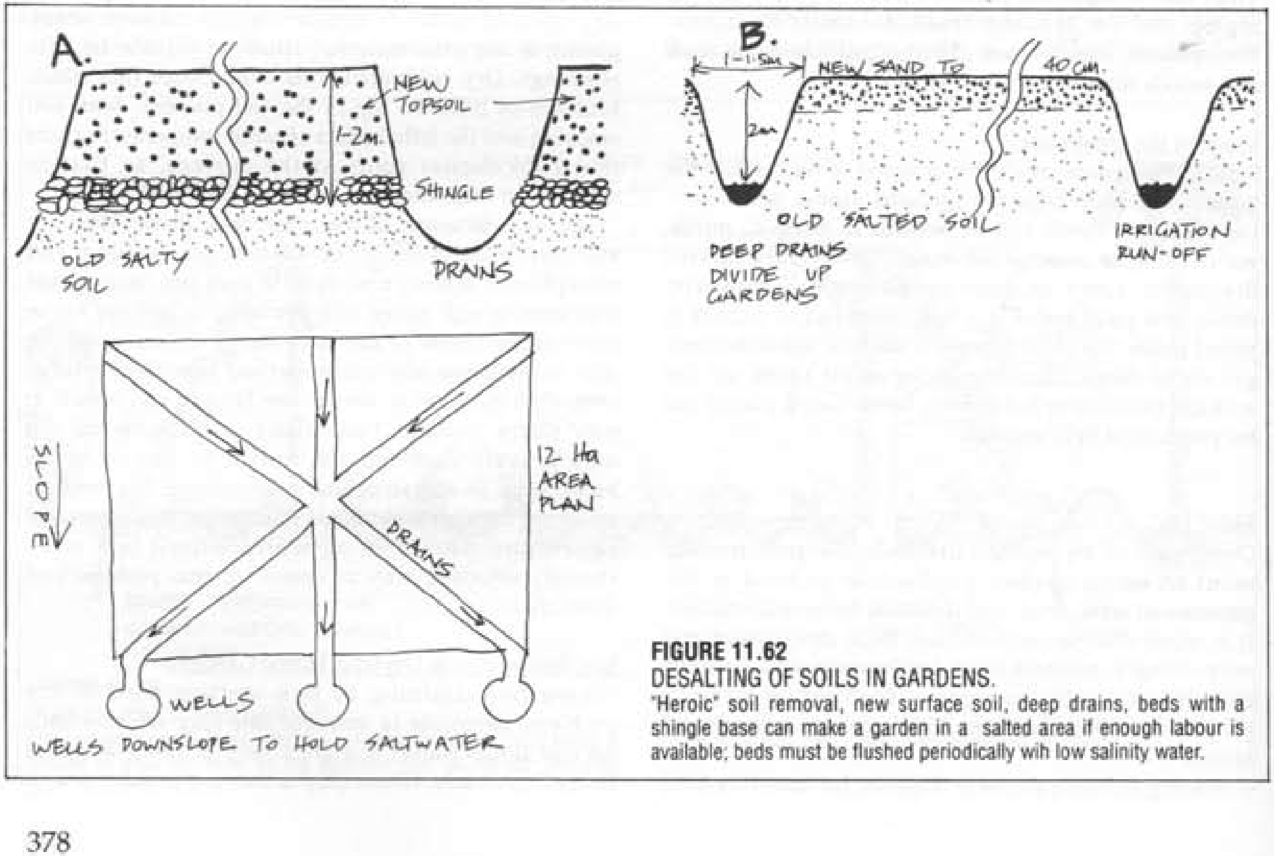


FIGURE 11.62
DESALTING OF SOILS IN GARDENS.
'Heroic' soil removal, new surface soil, deep drains, beds with a shingle base can make a garden in a salted area if enough labour is available; beds must be flushed periodically wih low salinity water.

• COLLECTED ashes, bones, dog, cattle or horse manure, kept dry or pitted in circle pits for in-ground compost. Ashes and dry herbivore manure can be shredded or pounded.

• FINES: chaff, bark, leaves, tea leaves, coffee grounds, flood detritus, rice or grain hulls, rotten wood, sawdust. All these "fines", and shredded paper or wood chips, are ideally combined with shredded manures, sand, and ashes to fill up raised beds; these can be laid as a top or coarse mulch.

• COARSE MULCH: logs, twigs, dry straw, thick bark, old wood. These are used as bed edges, or a 4–6 cm layer over which mixed soils and "fines" are spread to 18–20 cm thick.

• TOPPINGS: Seagrass, woodchips, pine or *Casuarina* needles, cocoa beans. These can be a mulch or cosmetic layer spread over the top of the early layers.

Our bed now looks like **Figure 11.63.**

Good green mulches for grapes and tree crop can be gathered from catch crops of lupins, fava beans, and coppiced *Acacia* or mallee eucalypt; these can be cut after rains, and stored as silage or in earth pits for later use. Lucerne establishes in swales and damp areas, and *Casuarina* leaf or pine leaf can be regularly gathered from trees in the field. We must largely rely on mulch to bring down the pH of alkaline soils and to make minerals available.

In mulch, free–living nitrogen–fixing organisms supply plant nutrients at a steady rate, and leaching is delayed or prevented. In tropic drylands, the greatest losses are in bare soil agriculture, when nitrogen, calcium, and potasium are leached to streams and groundwater. Wherever we use deep humus, mulch, or green manures, we need to provide dolomite, as nitrates prevent copper and manganese mobility if no calcium or manganese is supplied.

When we mulch in deserts, we need to emulate the ant and the termite, who bury their organic materials out of the sun. Wherever possible, we should also place a layer of stone, sand, or soil over our desert mulches, or create hollows where trapped leaves will be later covered with sand.

Drought stress in cultivated plants is greatly ameliorated if these plants are provided with mycorrhiza (root fungi). From the host plants, root associates get shelter (in a safe root environment) and sugars. In return, they scavenge for soil nutrients, and can mobilise phosphorus even at very low water levels in the soil. It is true to say that many plants don't have roots; they have fungal mycelia to explore the minute world of the soil particles.

With almost no exceptions, all the vegetables that

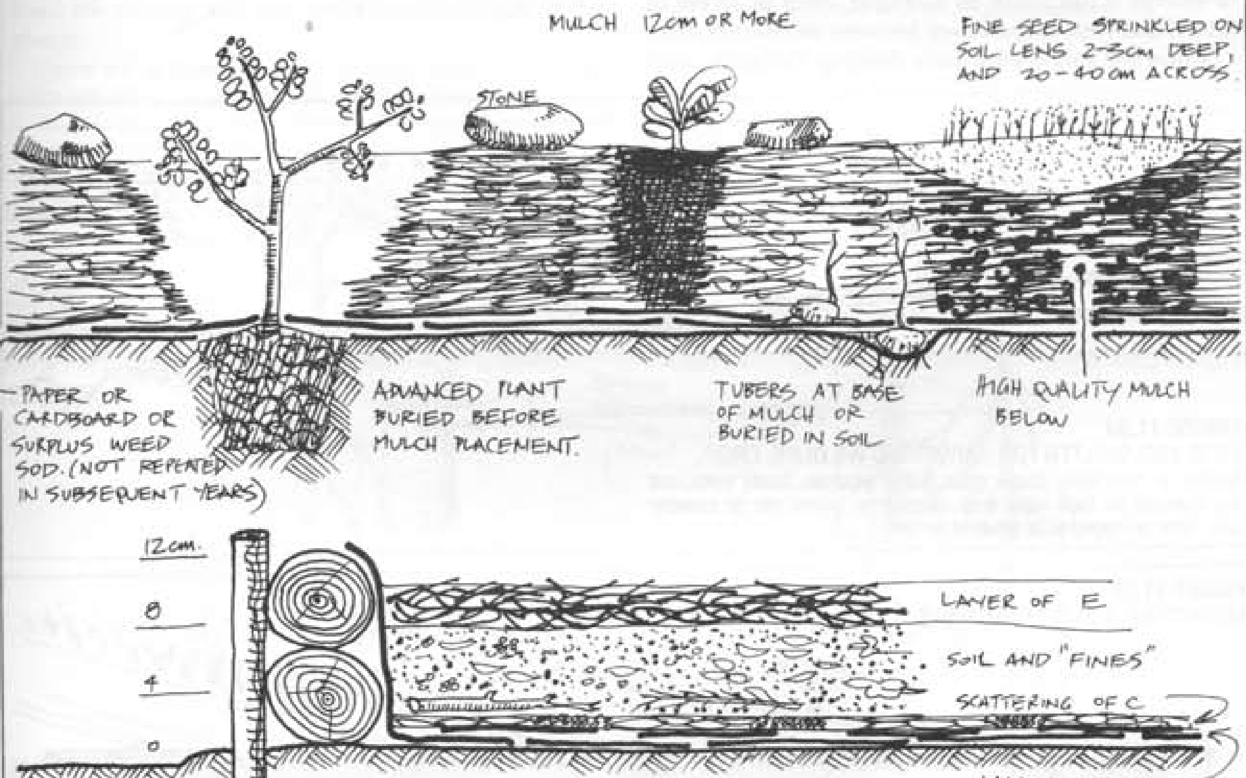


FIGURE 11.63
MULCHED GARDEN BEDS.
Very thick (18–20 cm) mulch conserves water, produces good humus soils; methods of planting trees, seedlings, fine seeds, tubers are shown. "Instant" gardens are made this way in drylands; all stages are watered as completed. Mulch is built up as in B.

grow in humid areas of similar temperatures will grow in deserts or dryland gardens under some form or irrigation or water harvesting. Field crops are more restricted, but grains, oil seeds (sunflower, safflowers) and grain legumes can be grown in suitable soils, after rains. Fields, however, are more expensive to modify and water than gardens, and carry the risks of wind erosion if cultivated. "Fields" in deserts may be possible as cross-wind avenues between perpetual windbreak of *Acacia* species and fieldstone. However, I have not as yet seen this tried, and even in avenues, the width would need to be restricted to 5 or 6 times in tree height, and all crop straw returned (trash or mulch farming) to avoid rain splash and soil loss.

Space is seldom limited in deserts, so that up to 30% of any garden or field can be profitably devoted to permanent or (for gardens) seasonal windbreak, as much for a mulch source as protection from the wind. Unburnt and ungrazed semi-desert can produce very large quantities of grass mulch after rains; it is quite frightening to stand in a chest-high stand of *Danthonia*, *Stipa*, *Themeda*, and *Agrostis* dried to a tinder in such conditions, and to contemplate the implications of a fire! I believe that a large area kept unburnt, and forage-harvested in strips after rains, would supply all the mulch that gardens could use. In the (narrower) unharvested strips, I would expect a dense mat mulch to emerge *if* fire could be excluded, even in 15 cm of rain. If this were rolled down between permanent trees, a humus soil would eventually develop. Certainly, all of these strategies should be tested (avenue cropping, forage or mulch harvesting of bunch grasses, roll-down mulching, and trash farming in avenues) on the broad scale.

If such systems are also combined with interceptor banks (**Figure 11.93**) it may be possible to develop a dryland agriculture based on permanence and stability.

The unregulated nature of grazing and wildfire is what prevents this development in many semi-arid areas Harvested wildlife would, however, appreciate the system for food and shelter. I have tried to diagram such a system in **Figure 11.64**.

On an eroded, alkaline, non-wetting sand dune near Ceduna (South Australia), a group of aboriginal students trained by Peter Bennett of the Soil Association produced in 6 months an excellent, healthy mixed garden of almost every sort of vegetable and many flowers at 1,100 ppm salt in water. The key ingredients were fine-shredded mulch, compost, and coarse mulch on beds, careful watering, and a sound organic approach to soils. Given such a hostile base for a garden, this example should encourage any group to do the same. The graduate gardeners from this teaching garden have extended their studies to home gardens in the area, and to teaching those skills. This is an appropriate way to provide food in deserts.

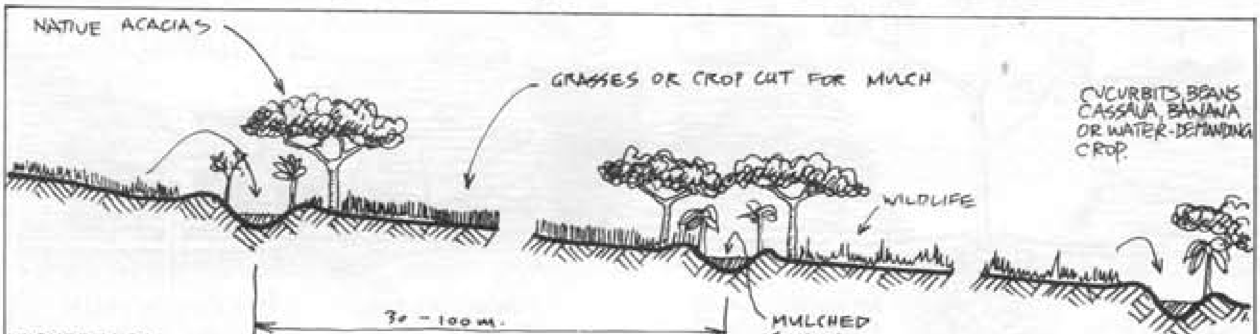
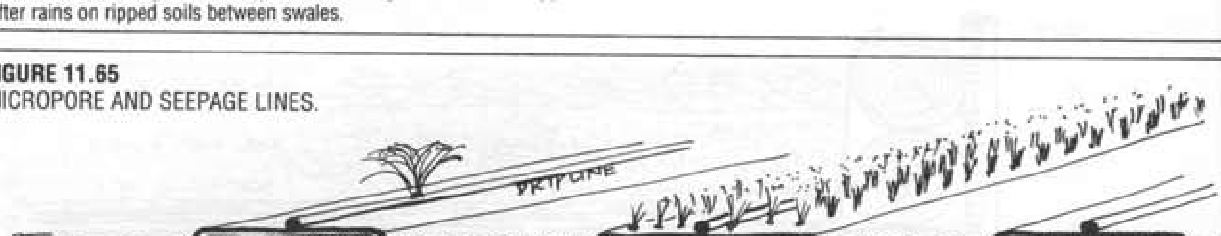


FIGURE 11.64
FOOD AND SHELTER FOR HARVESTED WILDLIFE, CROP.
Swales on headwater slopes grow fodder legumes, hardy trees, and are mulched for high value crop. Grasses or grains can be cropped after rains on ripped soils between swales.

FIGURE 11.65
MICROPORE AND SEEPAGE LINES.



11.9

GARDEN IRRIGATION SYSTEMS

The use of water in unguarded or unsheltered plots is wasteful, as a 10% increase in evaporation is possible on the edges of such plots. There is no doubt that trickle, drip, or seepage irrigation is *the* most effective dryland garden watering method. All we need to argue about is at what level of technology. The most sophisticated systems use automatic timers, 7- or 8-line sequences, and extruded plastic hose with drip emitters of various efficiency and flow rate; there is a vast commercial literature, catalogues, and even training programmes available from manufacturers.

The cost of a good dripline system amortises even in the lowest-paid western households in a few months, given the food produced. However, normal household water use is sufficient to water a good-sized home garden if the wastewater is led to underground seepage pipes and thence to plant and tree roots.

Now popular on a global level, drip-line systems have manufacturers and representatives in almost every country. Water use by drip, especially in orchard or tree establishment, can be from 10–50% of sprinkler use, and if trees are grown, species which are adjusted to climate need water only in the early establishment phase. The particular advantages are that only low head are needed, and that water is placed right at the plants.

There are at least two basic systems, one a solid line with emitters ranging from small sprinklers to drip emitters, and the other a thin, twin-pipe "Bi-wall®" system where a high-pressure pipe is joined and perforated to a low-pressure pipe which is perforated at intervals to suit row crop. Nylon mesh insert filters (or old stockings in a larger pipe) are used as filters, and automatic, soil-sensing, and nutrient addition, or timing systems can be added. This is the technologist's dream system, and installed with small in-line taps, can be laid to completely water the home garden. Even more sophisticated are systems devised to automatically respond to soil probes which sense dryness at root level by measuring soil ionic exchange capacity.

Drip irrigation is ideal for glasshouses and enclosed growing systems, but should be used with caution in waters of more than 800 ppm salt on bare ground, as local salts and carbonates accumulate at the plants. For trees, this effect is overcome by letting drips fall into stand pipes which let water pool at root level, not evaporate to air.

At modest level, people use unglazed earthen jars central to small circle gardens, inverted bottles with leaky tops, and short tubes of pebbles (hand-filled), plus bucket systems. These serve to let special trees survive severe drought conditions in home gardens, or to get windbreak going in deserts. Plastic "pillows" are on sale which can be placed as part-mulch, part-drip at valuable trees. Some pillow systems are designed as circular windshields and small glasshouses.

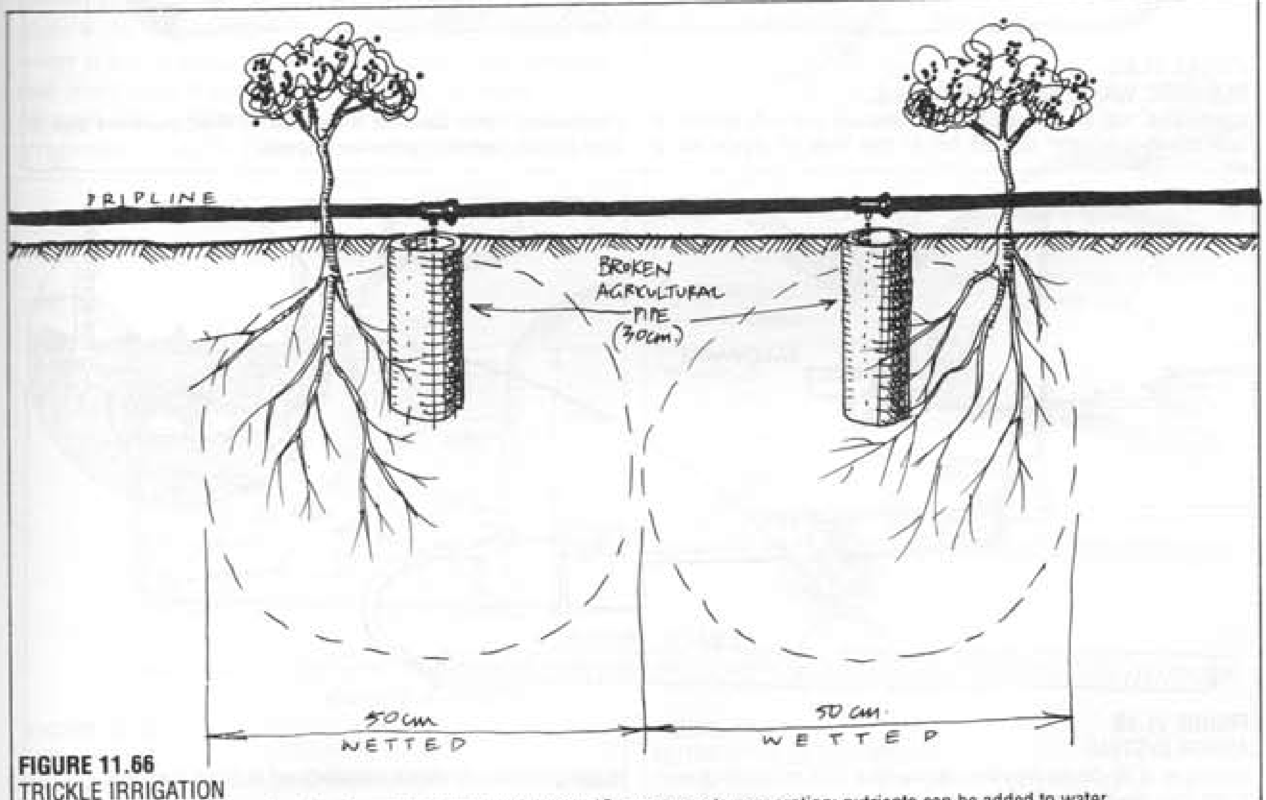


FIGURE 11.66
TRICKLE IRRIGATION
drips into pebble-filled clay pipes to allow water to wet soils below 15 cm, prevents evaporation; nutrients can be added to water.

SUBSURFACE IRRIGATION SYSTEMS

Underground drip and seep systems, if 12 cm or so below the soil surface, are the most conservative method of irrigation. These are best suited to arid sites, where solar evaporation is a factor, and on those sites, the critical use of water is to establish windbreak of desert-hardy plants around orchard or crop. There are good reasons for using domestic wastewater sub-surface, especially sewage water, and these have to do with health and soil filtration. Subsurface may mean below a plastic surface film for some crop like strawberries, and even deep below the soil surface for desert trees. Swales are the best example of cheap subsurface water development, but there are many special techniques successfully used:

• MICROPORE OR SEEPAGE LINES: these are for valuable row-crop, and have many slits which open under slight pressure. They can be laid below root level or (for shallow roots) at surface, and are worth the effort for such crops as strawberry, medicinals, special seeds (**Figure 11.65**).

• TRICKLE IRRIGATION PLUS POT OR PIPE: a very successful way to water arid-area tree seedlings. Shallow pipe can be replaced with deep pipe to 0.5 m as a tree grows (**Figure 11.66**) and the root zone extends Ideal for primary windbreak or ridge forests in the establishment years, but species that later stand alone should be used.

• DOMESTIC WASTE CHANNELS: used successfully off desert houses. A sheet of plastic is laid 30 cm below the soil surface from a wastewater outlet, in sands or very permeable soils, preferably 60 cm or less wide. Non-root crop is planted above the plastic, and the channel periodically extended so that no surface

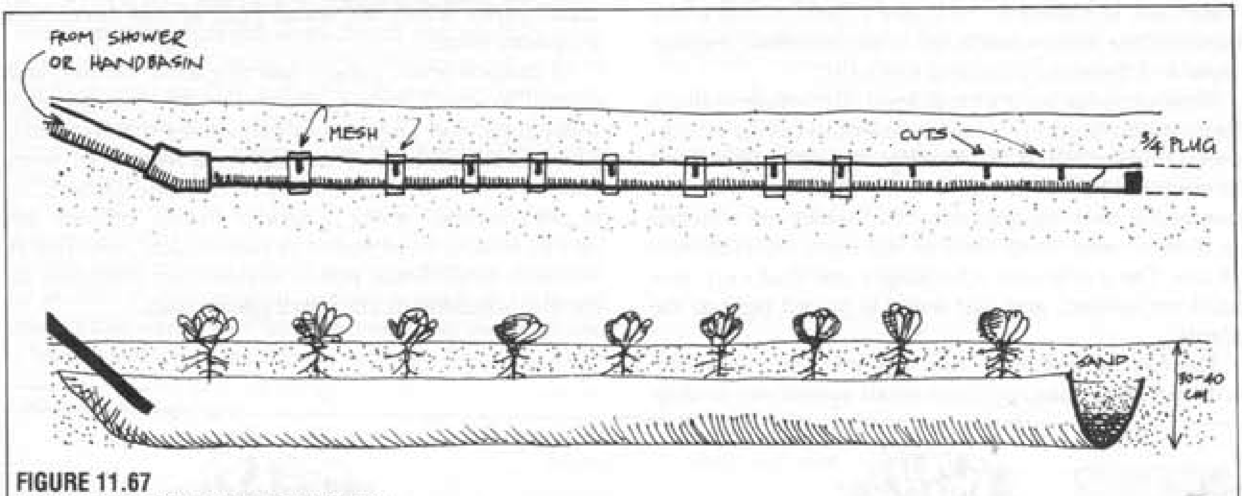


FIGURE 11.67
DOMESTIC WASTE WATER CHANNELS.
A level pipe, half cut through at 40 cm intervals and with screens at cuts allows greywater to seep out at root level of vegetables; a plastic-lined trench can help in deep sands. Rigid polythene pipe is good for this method of greywater disposal.

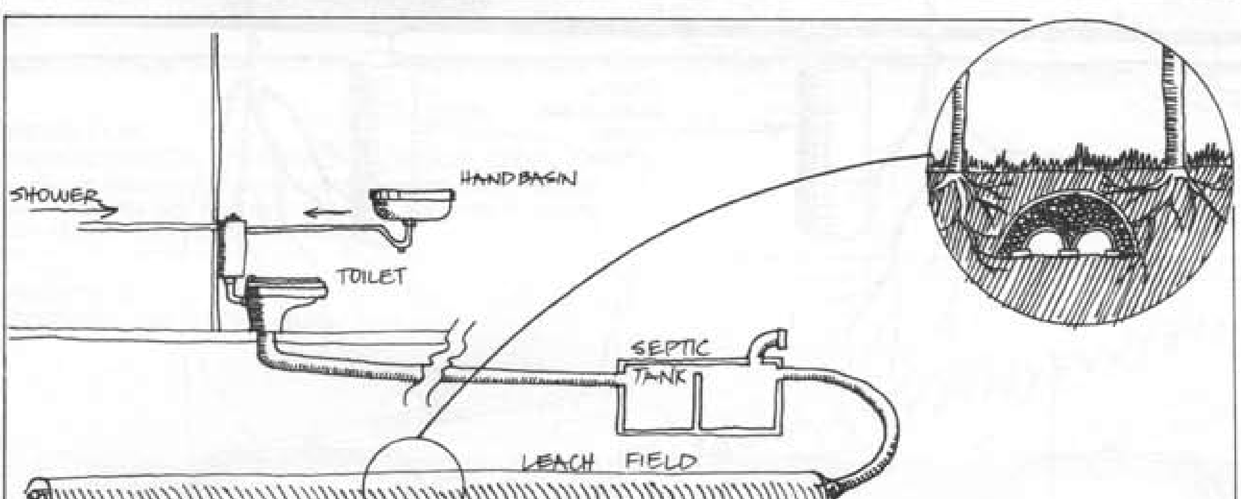


FIGURE 11.68
ARBOR SYSTEM.
Half-pipes of 20–30 cm diameter, crosswalls at 1.25 m. spacings each 4 cm high enables tree planting beside leach drains with no root clogging of pipes. System is manufactured in South Australia.

water appears. Slotted pipe can be used to carry wastewater along the plastic base of the garden beds (**Figure 11.67**).

• ARBOR SYSTEM: commercially available in South Australia, wastewater pipes will not fill with tree roots and can be used without gravel seepage beds in ordinary soils. Ideal for productive trees like citrus, apricot, and palms (**Figure 11.68**).

• POT SYSTEM is excellent for village gardens, with or without dripline. Combines well with circle gardens (**Figure 11.69**).

• HOME SLOT-PIPE SYTEM. The top of the pipe (3–5 cm diameter) has slots cut to one level, nylon mesh or old stockings bound around these, and wastewater led in from handbasins or sinks past a grease trap or crude sieve to catch solid particles. These are excellent too, for small-fruit beds, with the slots at correct spacing for plants. Pipes should be laid to one side of the plants for periodic checks as they do eventually block up. A half-pipe is sometimes used in the same way as the perforated pipe (**Figure 11.67**).

• NUTRIENT FILM AND INJECTION TECHNIQUES. There are at least techniques in use to prevent any water loss by soil absorption; both are essentially hydroponic-intensive. In Israel, direct infusion of water and nutrients into tree or vine stems (a nutrient drip) is in use, and in India a plastic film technique is used to grow Napier grass (*Pennisetum*) for forage, with part of the root mass in earth, part in a nutrient solution in the plastic gullies (**Figure 11.71.A**).

It should also be possible to "wick water" with a slotted pipe, using hessian or nylon wicks to nearby plant roots (**Figure 11.71.B**). In either case, little or no water is lost to soil, and plant roots can explore both the soil itself and the nutrient solution. In view of the obvious maintenance problems of such systems, drip irrigation in open fields and true hydroponics in glasshouses may be preferable if labour is not available for layout, maintenance, and harvest.

Sea or brackish-water can also be used at high tide level in lagoon for garden irrigation (**Figure 11.72**).

• AUTOMATIC IRRIGATION. In areas where electronic sensors are impractical or expensive, some such mechanical apparatus as that sketched in **Figure 11.73** would, in effect, permit automatic watering and self-regulate in rain, and ensure that irrigation is sufficient. Any capable local firm could make such reliable equipment. Rain automatically switches off the tap after 3 cm of downpour. **Figure 11.73** is designed from data from Kevin Handreck, CSIRO, Australia.

CONDENSATION STRATEGIES

Where no piped water is available, and where water is in seriously short supply, trees and gardens need condensation strategies. The aim is to condense water either from night air, from transpired water, or from weeds and trimmings, and return it to root level for re-use. The following methodologies are used:

1. Plant shields of plastic, mesh, or metal.
2. Stone mulches.
3. Sheet plastic sub- or surface mulches.
4. Organic mulches.
5. Pit evaporation systems.
6. Closed recycling systems.

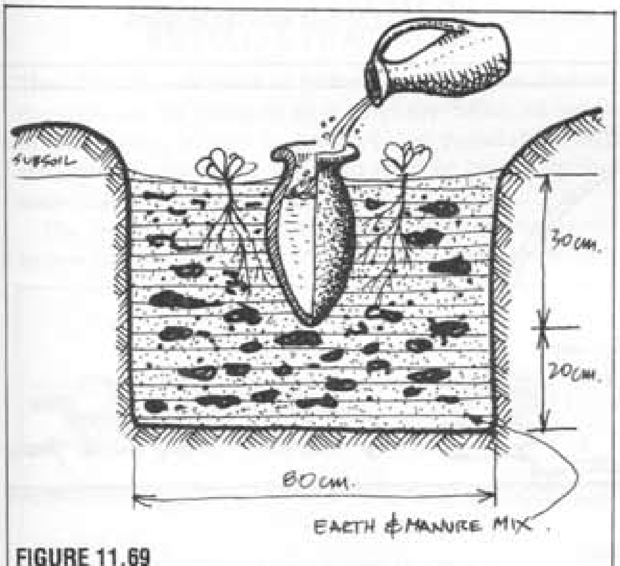


FIGURE 11.69
POT SYSTEM.
An unglazed pot in a humus pit waters a circle of vegetables in circle gardens.

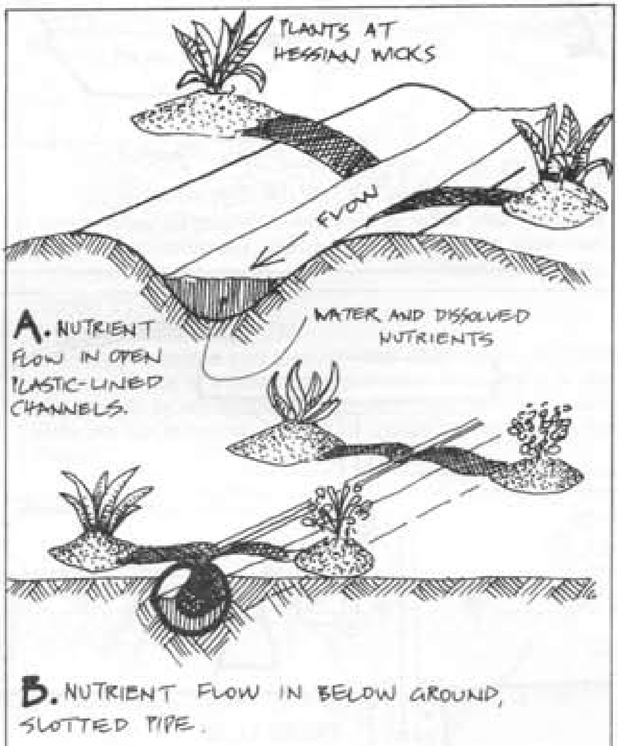


FIGURE 11.71
NUTRIENT FILM TECHNIQUES.
Hessian wicks part-irrigate plants from plastic trough or slotted pipe; used for valuable crop, somewhat salty water.

To take each in turn:

1.Shields of Plastic, Screen material, or Metal

Small trees, planted with a 3 or 4-stake frame over which a bottomless and topless bag is pulled, and around which loose weeds are placed, live in a protected environment in which, at night, soil moisture condenses and runs down the inner bag surface to the roots. Alternatively, coastal ridge areas can condense water from night air using fine metal screens or fences, placed crosswind.

Shields cut down wind, hold mulch, protect from plants from *small* animals, and condense water. My own experience suggests a difference of 80-90% in survival using shields as against unprotected plants. Growth (as light) may double in tall clear plastic bag tubes around a small tree.

2. Stone Mulches

Wherever stone is plentiful, stone mulch acts as a condenser, screen, weed control, windbreak, and root weight against windthrow. Small invertebrate animals take refuge in stone and add nutrient, and the ground below stone piles is always damp. Stones in walled circles on rocky hillsides, with weeds thrown in, are a very successful establishment technique, and can be moved after 2-3 years, or as plants establish. Even a few flat stones at a tree base assists with condensation of soil water.

Linear stone mounds between crops have a similar effect, and natural raised boulder beaches act very much as do swales, so that springs break out below them; they can be used to plant double lines of trees or crop.

3. Sheet Plastic and Sub-Surface Mulches

Sheet plastic, perforated for plants, acts as a ground surface re-condenser as do stones, and a variety of forms are in use (**Figure 11.74**) to trap moisture, reduce weeds, and condense night moisture. They integrate between closed recycling systems and open field mulches, and can be used indoors and out. The common uses are on small fruits and valuable crop, where costs are offset by income. As well, deep *vertical* plastic sheets prevent lateral loss of water around desert gardens, while buried sheet benefits from the weight, sun protection, and additional mulch of a layer

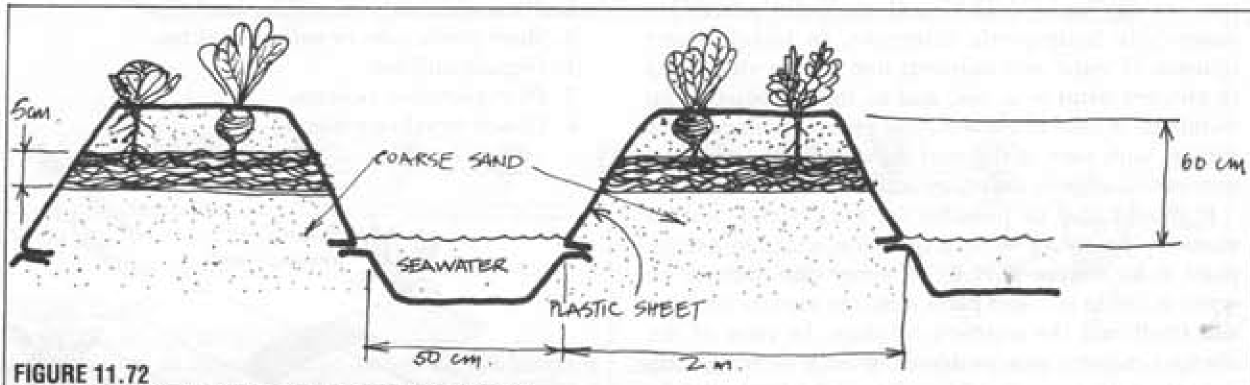


FIGURE 11.72
SEA OR BRACKISH WATER FOR GARDEN IRRIGATION.
Extremely salty water or seawater will evaporate under plastic to root-water plants via sand, peat layer. Warranted only in extreme conditions, in atolls, where no fresh water can be spared.

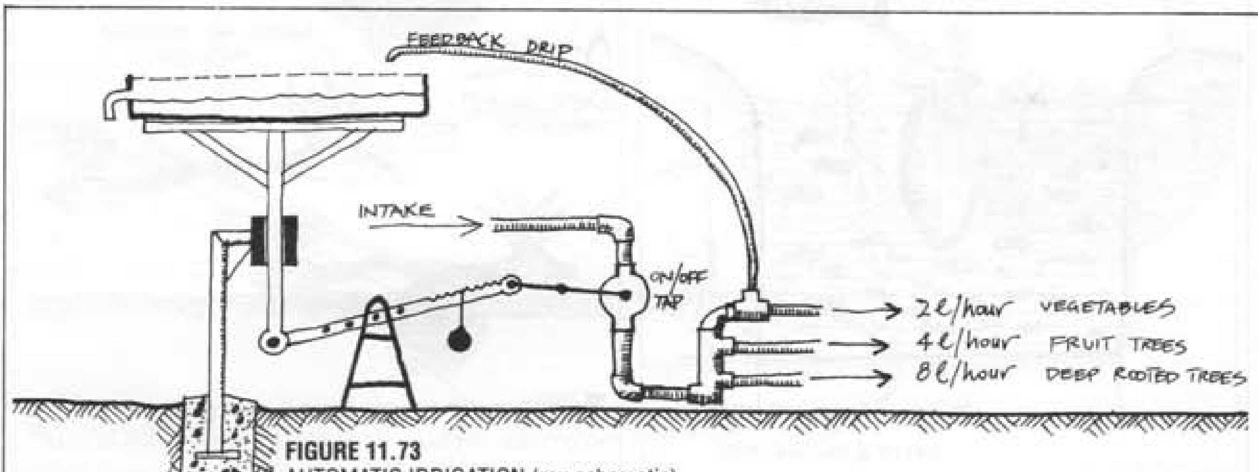


FIGURE 11.73
AUTOMATIC IRRIGATION (my schematic).
Pan evaporation is here used to switch on a manifold of trickle irrigation lines; feedback *and* rainfall is accounted for; a set period of irrigation resets the system.

of dry soil (**Figure 11.75**).

4. Organic Mulches

For very small areas or restricted tree sites, a variety of organic mulches are of great help. In extreme conditions, these need to be 45 cm or deeper to be effective, but in a drought summer, they may mean the difference between survival and death of plants. Special deep mulch boxes are excellent in forests or gardens for root crop such as yams and potatoes. Weed suppression, condensation or release of water, wind protection of soil, and decomposition products are all in effect, so that compound influences aid plant growth.

Combinations with plastic sheets, pits, and drip–line systems make mulches even more effective in home gardens. Small waterholes benefit from being thatched over, and many padi crops (taro, rice) can be grown in mulch with much less water use than open ponds.

5. Pit Evaporation Systems

These are used as survival strategies in deserts, but can be adapted to grow useful plants, using less useful or cropped plants to give up water, or salted water to provide fresh drip to plants (**Figure 11.75**).

6. Closed Recycling Systems

When it is feasible or economic to totally enclose plants, as in glasshouse and plastic tunnel systems, there are some water losses due to ventilation, but little else, as condensation on the inside surfaces can lead back to plants, or salt water flows can be evaporated to air before cooling the vapour to potable water fed to plants.

11.10
DESERT SETTLEMENT–BROAD STRATEGIES

The ultimate safe limit of human occupancy in deserts depends on the capacity of a carefully–balanced wadi or permanent lagoon to support that population. All settlements (ancient to modern) *must be limited by the water supply available to them.*

The majority of dryland settlements have managed, in one way or another, to destroy both themselves and their hinterlands. The common ways they perish are:

• To exceed the capacity of (or to pollute) local water resources.

• To devastate their environment for firewood and fodders for domestic livestock.

• To fail to govern their expansion, or to assess a limit to growth. Consequently (as with many societies) wars and invasions, or refugees and migrations, follow.

All these factors must be taken into account when we chose to live in drylands. I believe pastoralism to be one of the key factors in all arid landscape devastation. A very complete education in rangeland management, and a strict restriction of livestock numbers (constantly assessed) is necessary to enable any settlement to survive. If grazing is controlled, firewood supply and essential windbreak is also ensured, as is a basic food resource from local agriculture. But if we impose the

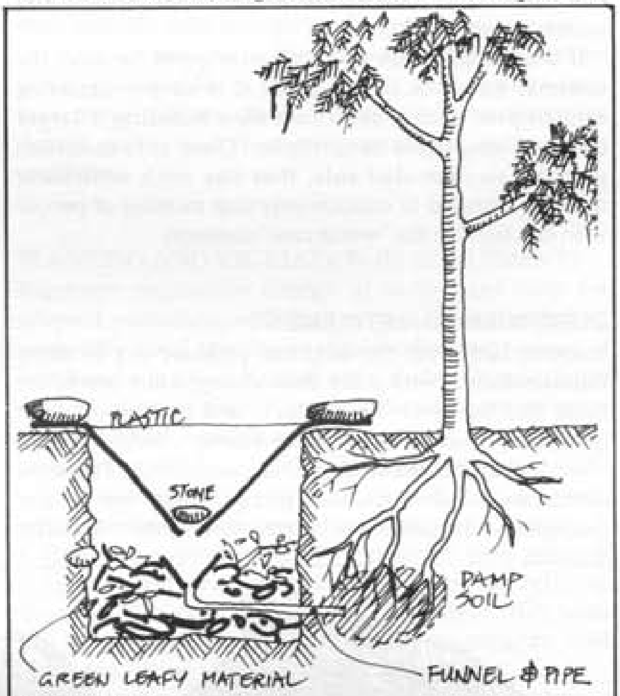


FIGURE 11.75
PIT EVAPORATION SYSTEM.
Green leafy material in a pit gives off water which condenses at night on the underside of a plastic cone, perforated at the centre to allow rain through; by adding fresh leaves, dirty water, or urine a nearby hardy tree can be sparsely watered, or enough freshwater for a drink obtained.

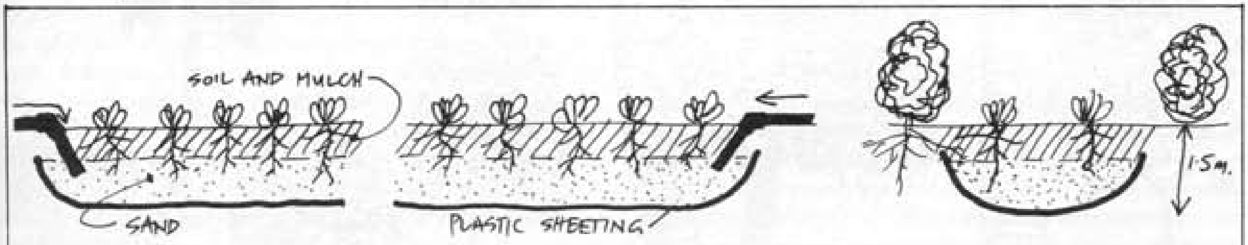


FIGURE 11.74
PLASTIC SHEETS AND SUBSURFACE MULCHES.
In very deep coarse sands, only plastic sheets will hold humus, nutrients, and water at root level of crops; gaps are left every 30 m in broadscale systems.

stress of ungoverned pastoralism on that of expanding settlement, we are inevitably doomed to create real deserts from drylands.

We need a very cautious approach to desert settlements, in that very favoured environments or refuge areas are limited. We must locate near water, or find water resources sufficient to our needs. In practice, this means one of three broad choices:

- The foothills of run-off uplands (about 5% of total drylands).
- Valley or wadi sites, at times under the shelter of cliffs and scarps.
- Around oases, permanent pools, or reliable exotic streams and freshwater wells.

Having selected such a site, we can do a great deal about firewood and water storage in settlement, and eliminate other undesirable factors such as dust and excessive heat.

If a settlement allows itself to expand beyond the minimal resources of dry years, it is simply deferring catastrophe, and at the same time building a larger order of long-term catastrophe. Thus, it is essential, perhaps an iron-clad rule, that any such settlement must be founded to contain only that number of people who can survive the "worst case" scenario.

DUSTSTORMS IN SETTLEMENT

Summer heat over the land can produce dry or rainy thunderstorms, with a dry downdraught just preceding them that can reach 50–65 km/h, and picking up great quantities of dust. Episodes of strong winds are most common under these unstable conditions. The dust devils, or whirlwinds, that precede them are milder examples of instability, occurring with great regularity at about 3 p.m. onwards in bare deserts in summer. Even a small ground movement, such as an antelope running or a car, can set off an upward spiral of superheated air. It needs a great bubble of hot air to rise in order to start a dust storm, which is then sometimes followed by heavy rains. Once a desert storm is initiated, however, the dust itself efficiently heats the air and perpetuates the initial instability, clearing only at nightfall or if clouds obscure the sun.

The effects of such storms near settlement can be greatly reduced by sealing roads, orienting dirt roads across-wind, erecting fences, ploughing lines, or pitting plains for grasses (all strategies to roughen the ground and so reduce effective windspeed).

No settlement should be planned without these attentions, or life can get miserable every time a car drives out of town, and both asthmatic, eye, and sinus problems can become epidemic. Dust carries a host of human pathogens, and dust storms are often followed by episodes of morbidity in settlements. Tree lines at 20–30 m are permanent solutions, and these can be established using town wastewater. Trees are best selected to be useful to the region.

HEDGES AND WINDBREAKS

Within the broad windbreaks of settlement, grown on swales and wastewater, garden hedges serve a multiple set of functions:

- To provide forage for poultry, rabbits, and bees.
- To shelter tall crop such as corn.
- To provide mulch from clippings and leaf fall.
- To exclude rampant grass or weeds from garden beds.
- To help exclude browsing animals or large live-

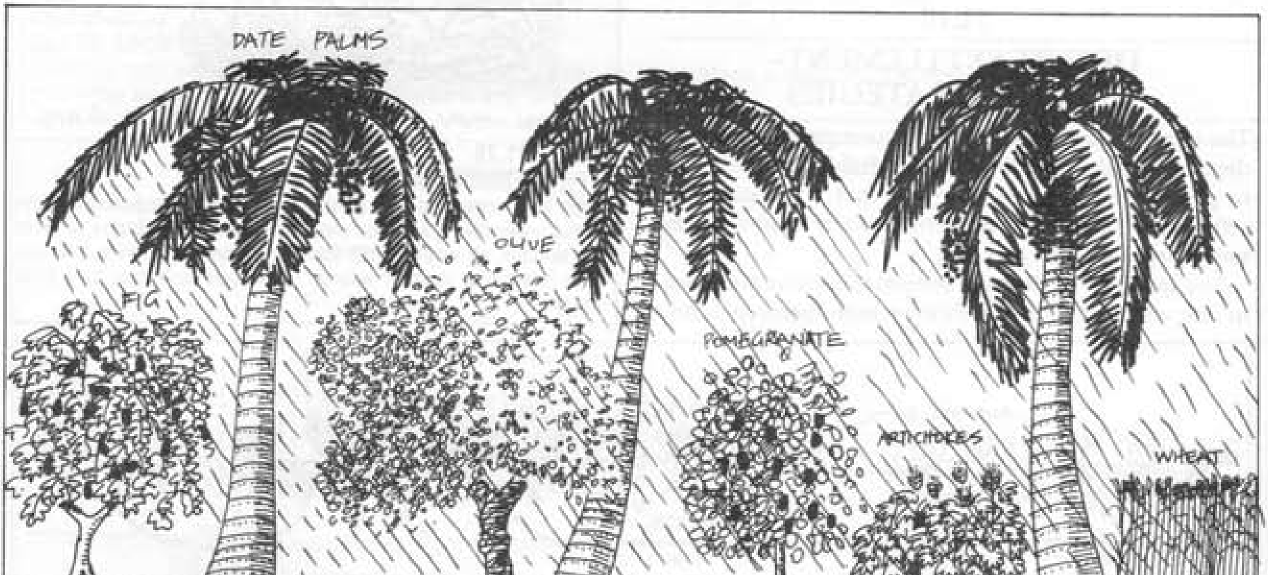


FIGURE 11.76
WILLIAMS' DESCRIPTION OF NORTH AFRICAN POLYCULTURES.
Palms as high shade over other tree and surface crop.

stock.

Careful selection of a mixed windbreak can achieve these ends. In very dry areas, it is prudent to set out a vertical (to 1 m deep) plastic root barrier between garden and windbreak to minimise water competition, to choose highly drought-adapted windbreak species, and to regularly check on root invasion while trimming hedges for mulch. Soft foliage from *Acacia, Casuarina, Prosopis, Leucaena, Albizia,* and *Coprosma* are ideal compost mulches, and some species provide good leaf fall. An investigation of local flora often yields up many suitable species. Outside such soft forage hedges, cactus, *Euphorbia* and thorny shrubs help exclude livestock.

Hedges within the garden are also of great importance, but can be of smaller hardy perennials (rosemary, lavender), crop species (sunflower, sunroot), or mulch species *(Crotalaria).* Fleshy vines on fences are ideal in crop windbreak *(Mikania, Dolichos).*

The total integration of house and garden is important. Even in very poor countries, the space between and close to houses (an area rich in nutrients, close to hand, and easily shaded and watered) is often left unplanted, while people "go to fields to work"!

The grape, passionfruit, a great variety of beans and peas, cucurbits, yams, and vine fruits, forage vines for domestic rabbits or guinea pigs, and vines providing honey and pollen are all desert or dryland adapted. Even in the sub-arctic, the silverberry *(Actinidia arguta)* provides copious fruit crop, and survives hard winters.

Below the thinned or well spaced canopy of vines and palms (date or doum palm) gardens are protected from direct sun and the drying winds.

> The long serpentine trunks of the palm tree rise above every village and about every field. The fibrous palm has entered almost every facet of the peoples' lives. It is the first line of defence against the sun in the open fields, and in its shade grows the olive tree. Under the olive, the fig grows, and under the fig, the pomegranate and vine, then the grain and vegetables. The palm tree's second contribution is dates...
>
> (Williams, C., 1974, *Craftsmen of Necessity,* Vintage Books, N.Y.) See **Figure 11.76**

Defining the desert garden, this strong hedge or fence is essential. If the hedge supplies clippings for mulch pits, compost, and potato boxes so much the better. A fast, but temporary, hedge can be made of banna grass *(Pennisetum)* which can be cut for mulch. It needs irrigation to keep productive, so is furrow-planted on manure. Parallel to this, a slower, hardier permanent hedge of columnar cactus or *Euphorbia* repels animals, and thorny *Acacia* also helps. One of the best in-garden "fedges" (fence-hedges) is a strong rail and wire fence (the post termite-resistant or creosoted) to carry vigorous vines such as *Mikania,* which provide soft mulch and bee fodder. *Dolichos* beans, lima beans, and passionfruit can occupy parts of these fedges, as can vigorous soft vines of other species. At 1.5-2 m high, the fedges protect 9-10 m widths of garden.

Outside this system again, taller slow windbreak of Roman cypress, *Casuarina,* or *Acacia* on drip provide high windbreak, but only if space allows. Olives may also establish; local hardy evergreens can be chosen for these 25-50 m grids.

We need to make a gradation from crops and grazing to tree products and forages, for as trees are the nutrient storages of the humid tropics, they are the ground-water moderators of the drylands. We are not short of tree species with which to do this, and if we have enough trees planted, modest grain and pasture strips can also be developed. Our error has been to develop grain foods at the expense of trees, and to extend grasslands and crops until we create desert, or to destroy trees until the salts in desert soils create surface crusts.

I cannot stress too often that wherever we harvest water, it should be to create forests. Not to plant trees may mean that we create waterlogged and anaerobic desert soils, and thus perpetuate or extend salt problems.

PLANTING AND VEGETATION IN SETTLEMENTS

Rigorous vegetative design of settlement calls for adapted perennials, both for food and shade, hardy and preferably local species in shrubberies, large areas of overhead vine trellis, and only a strictly regulated amount of lawn. Such lawns can be of *Lippia* or other carpeting and drought-resistant plants. Golf courses, extensive grass lawns, car washes, and large open pools or ponds supplied at public cost are dryland disasters which need to be taxed out of existence in arid lands.

There are many very hardy and useful trees needing only a swale nearby to survive years of relative drought. However, even water-dependent fruit trees can be grown in or near swales, in courtyards, and along road fitted to harvest water run-off.

A critical settlement strategy is to develop broad (300-400 m deep) tree parks around or even within the settlement, to eliminate not only the devastating dry desert winds, but also to help provide fuels, mulch, medicines, and to supplement domestic animal forage. This planting is the first line of defence against the desert; within its shelter, gardens and crops can thrive without wind damage or excessive water loss (**Figure 11.77**).

What Jen-hu Chang (1968) calls the "clothesline effect", or the effect of (advected) dry hot air blowing into crop, is of particular concern in desert gardens. A general ring of trees of *50-100 m deep* is needed at the desert borders of cultivated land, or the desert becomes self-propagating. The effect decreases exponentially, so that such a broad guard forest against desert creates a screening which effectively protects crops or cultivated lands from the dessication for a great distance downwind.

In such cases, it is better to establish deep tree belts around settlements against the prevailing desert winds, and to relax to smaller single tree-width shelters within the area so protected, rather than to place narrow windbreak throughout the crop or garden. Given that we can shelter the crop, and that the advected effect is reduced, we are left only with the "oasis effect" of moisture loss to atmosphere, due to earth heating by trapped resident hot air. In this case, field size is irrelevant as all the field is affected, and we have to accept the water loss, unless fields are so small they can be trellised or overshaded by leguminous trees such as *Prosopis*, or similar high shade trees.

On a national scale, it is imperative to provide tree belts 1–5 km wide on the savannah edges of deserts, or advected hot winds affect crops for hundreds of kilometres into humid areas, and bushfire frequency is then steeply increased.

Finally, very large buffer zones of ungrazed or lightly grazed desert can be developed around villages. Pitted or swaled, these areas completely defend against dust, so ensuring that both public and environmental health is preserved.

The last area of settlement vegetation to plan is that of FUEL FORESTS for cooking and (if necessary) power supply, essential oils, mulch, and other tree products such as honey. If the settlement is sewered, then surplus greywater and sewage can be first ponded in deep (to 3 m), narrow, preferably roofed or trellised, and well-sealed collection ponds, then led by dripline to a carefully selected and designed fuel forest. Such a system is in effect at Yulara, near Uluru (Ayres Rock) in Central Australia; here the river red gum *(Eucalyptus camaldulensis)*, Casuarina *(Casuarina cunninghamii*, and trees adapted to root water in drylands form fuel forests surplus to settlement needs.

Such a fuel plantation needs two elements:

- A grid or matrix of perpetual long-term forest no more than 300 m apart, nor less than 8 trees wide, initially established by trickle irrigation but selected to be very hardy on rainfall alone once established.
- In the sheltered spaces so developed, a grid of closed-spaced trees (2–3 m) on trickle irrigation pipes (preferably on automatic) which are harvested in a 4–6 year rotation as coppice.

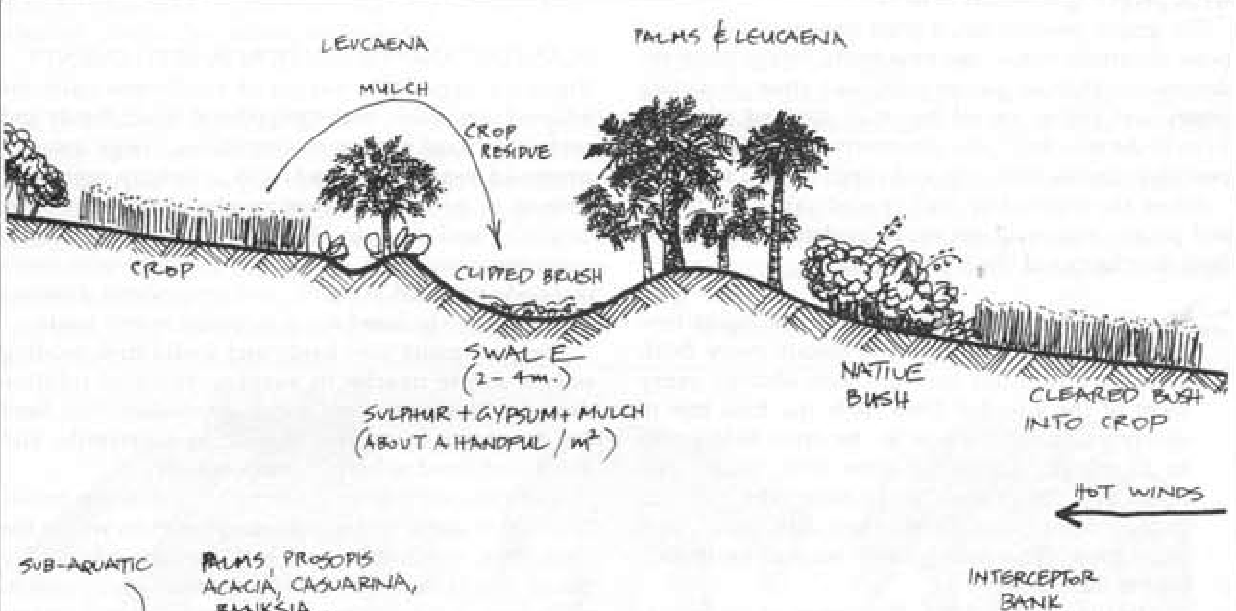
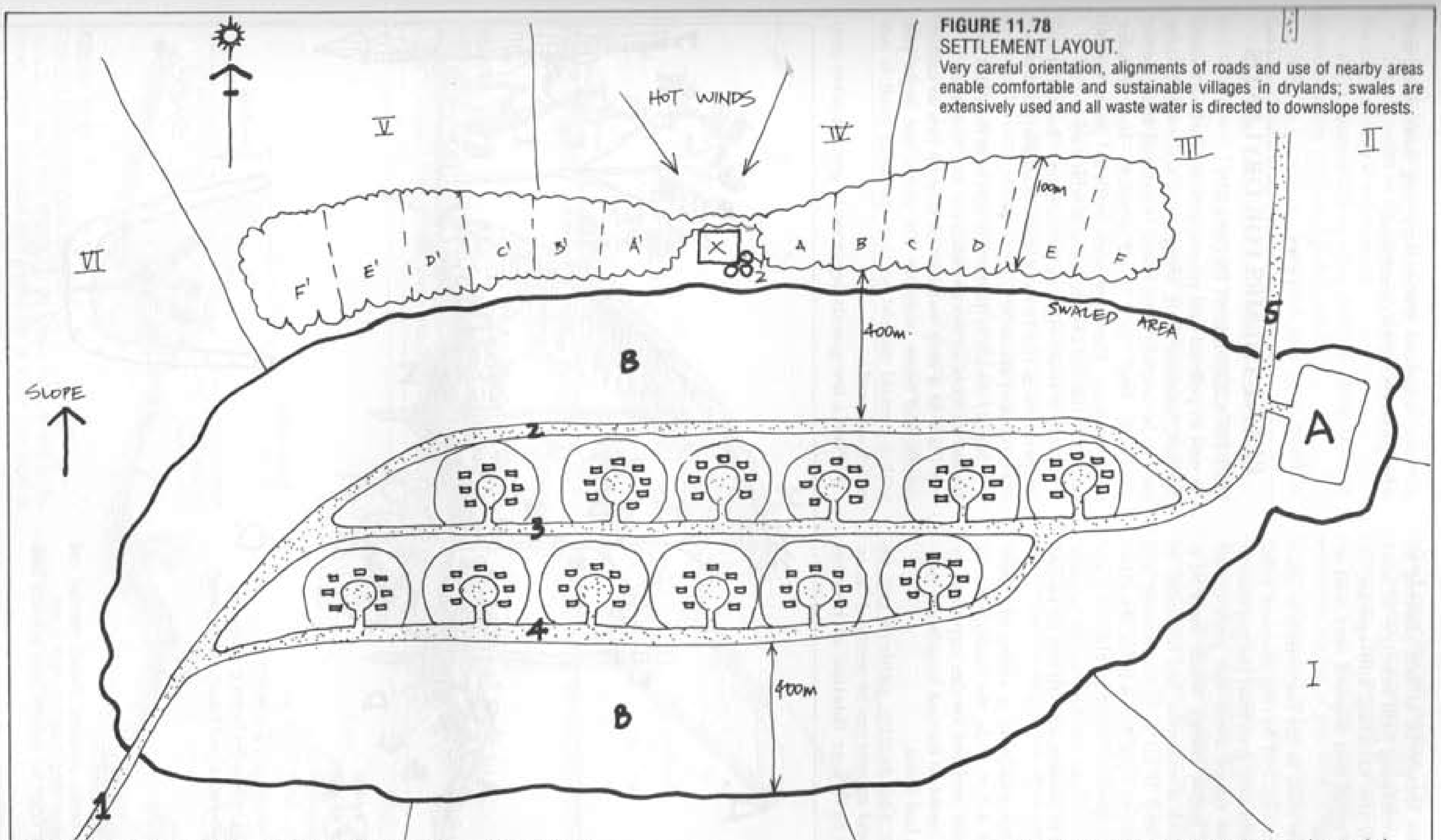


FIGURE 11.77
FIELDS IN DRYLANDS.
Need windbreak every 30–60 m, and scattered in crop; swales assist tree survival, and trees decrease "clothesline" effect of winds; leaves manure fields and swales.

FIGURE 11.78

SETTLEMENT LAYOUT.

Very careful orientation, alignments of roads and use of nearby areas enable comfortable and sustainable villages in drylands; swales are extensively used and all waste water is directed to downslope forests.



A–F and A'–F': Sewage or swale–fed fuel forests on 6–year rotations, surrounded by belts of perpetual forests. Gravity flow of sewage or swale/diversion water to this site.

X, Y, Z: Primary digester and settling ponds, chipper for organic wastes, alcohol ferment digester and methane engine house. Clear water routed to fuel forests after secondary settling.

A: Commerce centre, car park, trellised lanes and shaded park. Commerce and offices also permitted and encouraged in private housing.

B–B': Windbreak forests 400 m deep sheltering settlement and preventing dust and dessicating winds.

I–IX: Pitted, planted and maintained rangelands fenced out of the settlement, to provide essential animal products on long–term rotation of large livestock.

Y: Livestock yards, milk sheds, shearing sheds, also recreation grounds in this area.

1. Entry road(s): Sited to enter downslope and crosswind

1. Entry Road(s): Sited to enter downslope and crosswind (swales leading off the road to forests). No dust can blow from this road to housing.

2, 3, 4: Narrow east–west through–roads, tree–shaded and swaled. Swales to accept town water. Only very narrow and sinuous laneways connect these streets.

5. Exit road(s): Serves domestic livestock yards. No dust can blow into the settlement from this road. Swales to forests.

All fuel tree species should be at first selected as coppice types, and continuing field selection of seed can then proceed for the varieties, sub-species, or provenance (locality) types that respond very well to this form of cultivation.

Keeping in mind the need to cut one-fourth or one-sixth of the crop annually, and having assessed solid fuel need per household (*and* governed the population level), such coppiced forest areas can provide all essential cooking and public energy needs; more so if the settling pond or tank is anaerobic and harvested as a methane source, and if all organic wastes are shredded and added to this tank. Much of the shredded organic waste will support ferment to alcohol fuels before being routed to biogas production. *No* organic matter can be wasted in deserts, and all can be turned to productive use.

Where sewage is not available, a series of close-spaced swales of from 4–8 m wide, the banks between them only 3–5 m wide and the swales supplied by extensive interceptor banks to harvest broadscale run-off will also support a fuel forest.

Within settlement and nearby, gardens can be established for food, and an area can be reserved (as an outer zone) for a 6 to 9 year rotation of needful domestic rangeland species supplying meat, wool, and other products can be established.

11.11
PLANT THEMES FOR DRYLANDS

TREE ESTABLISHMENT IN DESERTS

As well as pelleted and pit-trapped seed which awaits the rain, valuable fruit, forage, and seed-source trees need to be carefully established in dryland areas, partly as graft, bud, and seed sources for broader reafforestation. There are some essential precursers to success in this endeavour, some of which are:

- Plant in relatively cool periods, and check that soil temperature is not lethally high. Shallow plant roots can be cooked above 30°C.
- Supply mulch in quantity in pits near the plant and around its roots, or stone-mulch the tree root areas.
- Plant in a long swale or in sloping pits to collect, absorb, and retain moisture. For citrus, use larger pits with a central mound so that the stem graft is not mulch-covered.
- Plant a few gourds, legumes, or ground cover crop

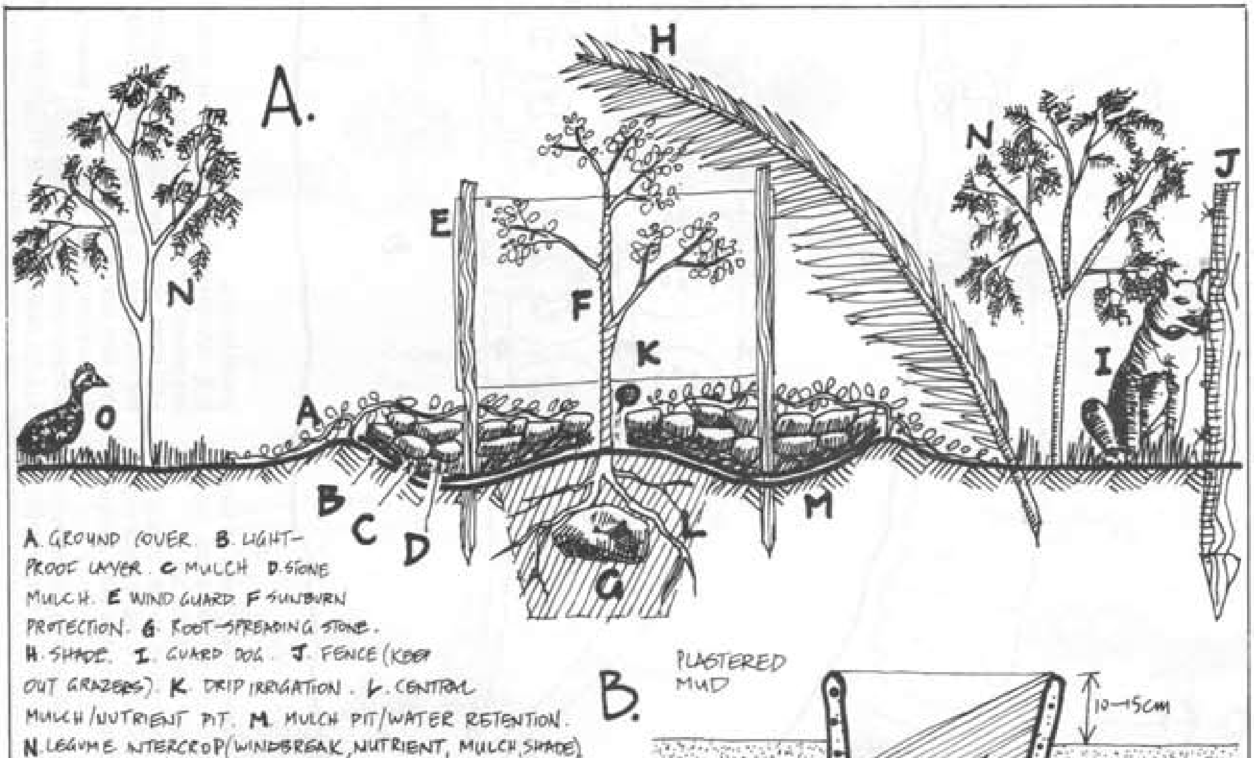


FIGURE 11.79
TREE ESTABLISHMENT IN DESERTS.
A. The "perfect" planting is fenced, protected, shaded, mulched, and has conservative water irrigation fitted to wet 1 m depth of soil.
B. Mud-lined pits used in Egypt for valuable trees prevents sand collapse.

around the tree to cool the root area.

- Supply water as drip for one to two years, or until the tree root area is self-shaded.
- Paint stems white or wrap them in foil to prevent sunburn before the bark has thickened.
- It helps to place a shade such as a palm frond or dead brush on a slant over the small tree.
- Fence the area, or shoot or poison rabbits, hares, and feral goats. They can wipe out a young plantation. Dogs keep all these away.
- Plant hardy tree legume intercrop to aid with wind, sun, fertiliser, and mulch.

Many of these features are summed up in one diagram, as in **Figure 11.79**.

In **Figure 11.80.B**, night condensation stays longer in the morning, enabling plants to use the moisture longer. In **Figure 11.80.A**, the morning sun evaporates night dews and plants suffer longer water deprivation. The heat itself is less a factor than water early in the day.

On Lanzarote in the Canary Islands, pits 8–10 m across and 1–3 m deep are dug, and one vine or tree planted in each. A cover of cinder is then carefully raked over the pit surface. The large pits act as night condensers, trapping cold night air and hence condensation. This method is also used for potato ridges, orchards in sloping country, and home gardens wherever cinder is plentiful. Over clay or loam soils, cinder allows rain in but prevents erosion and soil overheating. As cinder contains many air pockets or gas bubbles, it retains moisture from dews and condensation (**Figure 11.81**).

Apart from dune stability, palms and trees near groundwaters can be pit or slot-planted in a "mud planter" hole with effective avoidance of sandblast, water conservation (in the mud and the sand) and escape from the excessive heat of shallow sands (70°C).

This can be line, drip, or pot-irrigated; the mud (of course) must be locally available, and the whole process is worthwhile only if the trees are themselves of great value.

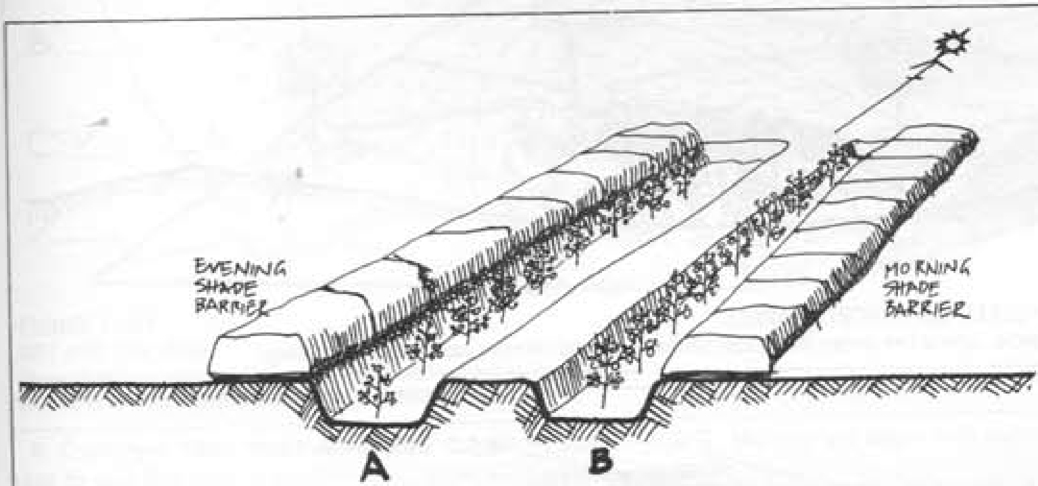


FIGURE 11.80
PITS AND HOLLOWS SHADED FOR MORNING SUN.
Small-scale growing of seedlings greatly benefit from shade. If water supply is adequate, trenches help shade crop; beware salt build-up if no flushing is possible.

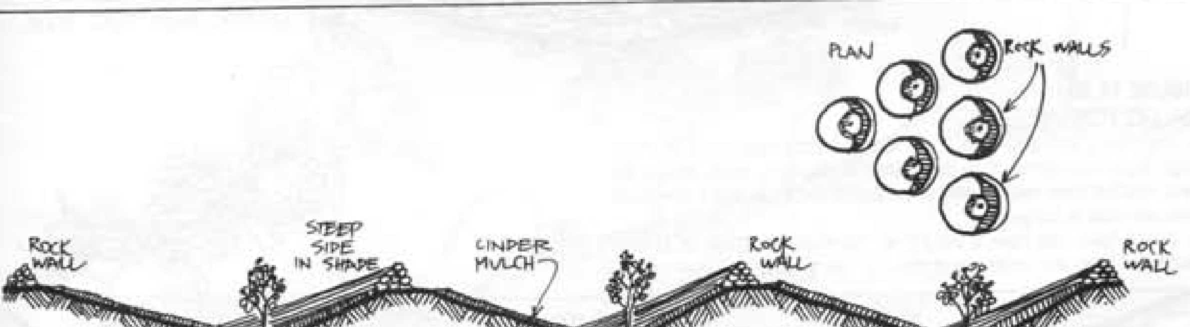


FIGURE 11.81
LARGE LANZAROTE CONDENSER PITS.
On a larger scale than FIGURE 11.80 cinder-covered pits on the Canary Islands (Lanzarote) each grow a tree or a vine; cool night air condenses enough moisture from sea winds to wet root areas.

SPECIAL PREPARATION OF SOILS FOR TREE PLANTING

Deep-cracking clay soils will leave small tree roots in the air, and the tree will die. It is better to collect a modest amount of sand from river beds, wait until rain is expected at the end of a dry season, and having soaked the site, or run rip lines across it, set out the small trees in sand poured into the clay cracks. Gypsum aids root penetration in such clays, which are sometimes acid in the plains areas. For hardy pioneer species, pelleted seed and sand in clay cracks suffices (tagasaste, *Acacias*, pioneer legumes).

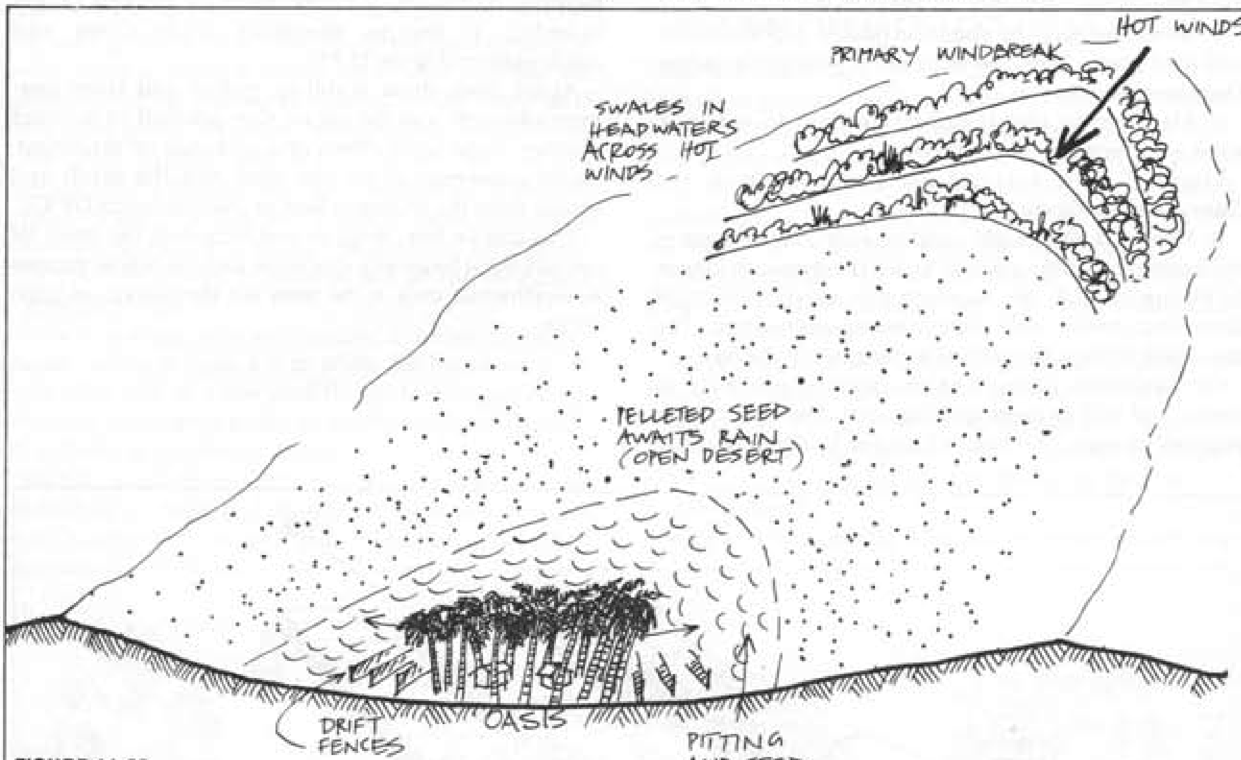


FIGURE 11.82
STRATEGIES FOR REVEGETATION OF HOSTILE AREAS.
Small *headwater* runoff areas; *upwind* tree swales; *broadscale* pelleted seed; and intensive *oasis* nucleated plantings.

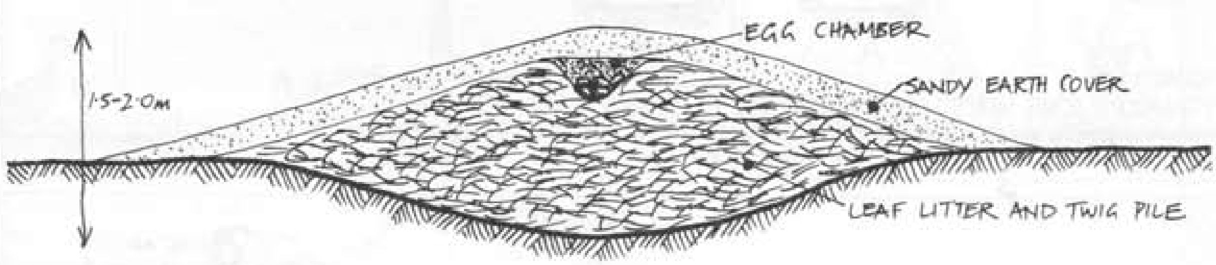
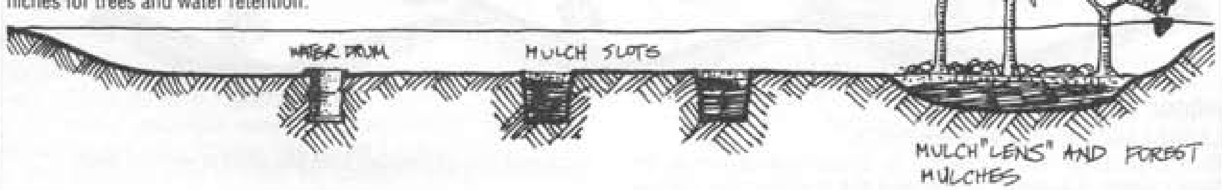


FIGURE 11.83
MALLEE FOWL NEST.
A. In effect, a compost heap. Pack rats and stick nest rats also make large nests in drylands; if we duplicate this structure, water held in the heap enables trees more suited to rainforest to be planted if rainforest soils are used in nurseries.
B. Swale base can have a variety of "furniture" or trials of special niches for trees and water retention.



In the calcrete soils of coasts and islands, the concreted layer must be broken open at every important tree site (as it is with coconut and date crop) and a mulch pit (plus a scatter of elemental sulphur and mineral elements) prepared for the tree. A few fibrous-rooted species will sit on calcrete, but they are then at risk from drought and windthrow. Tree growth keeps the *platin* open and cracked for interplant. A fast way to do this is with an auger and about one-third of a plug of dynamite. The same technique can be used to place fence posts, or to shatter concretions for tree holes in shales and mudstones.

Sometimes a bulldozer is available, and rip-lines can be made for the tree lines. In this case companion crop of small legumes can be seeded between trees along the rip. Desert fenugreek, lucerne, tagasaste, and gourds can be intercropped with palms, *Casuarina*, or jujube.

Just as gypsum helps roots to penetrate clay, bentonite assists sands to hold moisture. Dried seaweed crumble added to planting holes forms a gel in rain, and enables the seedlings to penetrate to deeper levels in the first season. Commercial soil gel additives are also available for adding to the soils of potted plants in the nursery, and some of these function for many dry-wet cycles in field conditions.

THE REVEGETATION OF HOSTILE AREAS

It is certain that we will need to reclaim dry, salted, deflected, and pest-invaded areas in the course of developing a permaculture. Let us return to the practical experience of people who try to re-establish native bush on disturbed areas covered with weeds. The lesson is to start with *small* nucleii and to gradu-

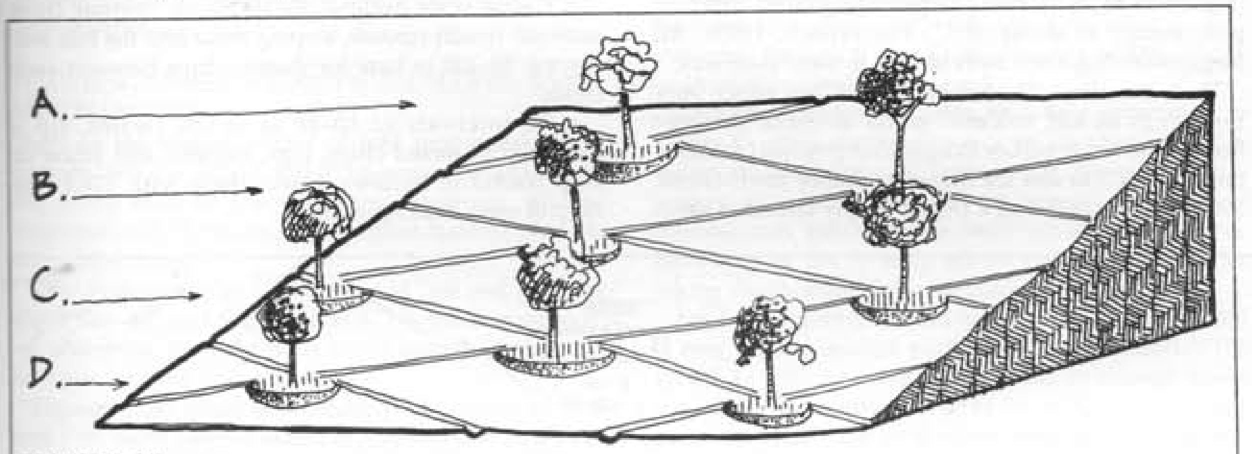


FIGURE 11.84
NET AND PAN (Plan).
Stony hillsides suit "net and pan" tree planting; hardier trees are planted in up-slope skeletal soils, less hardy trees on lower slopes.

A. Crest trees: hardy needle-leaf species and narrow-leaf trees to suit thin soils, e.g. stone pine, olive, *Casuarina*, *Callitris*, *Acacia*, quandong.

B. Hardy trees with known drought resistance, e.g. fig, pomegranate, *Acacia*.

C-D. Midslope and deeper soils suited to citrus, fig, *Acacia*, pistachio.

E-F. Deep base soils with some humus suited to chestnut, mulberry, raintree, citrus.

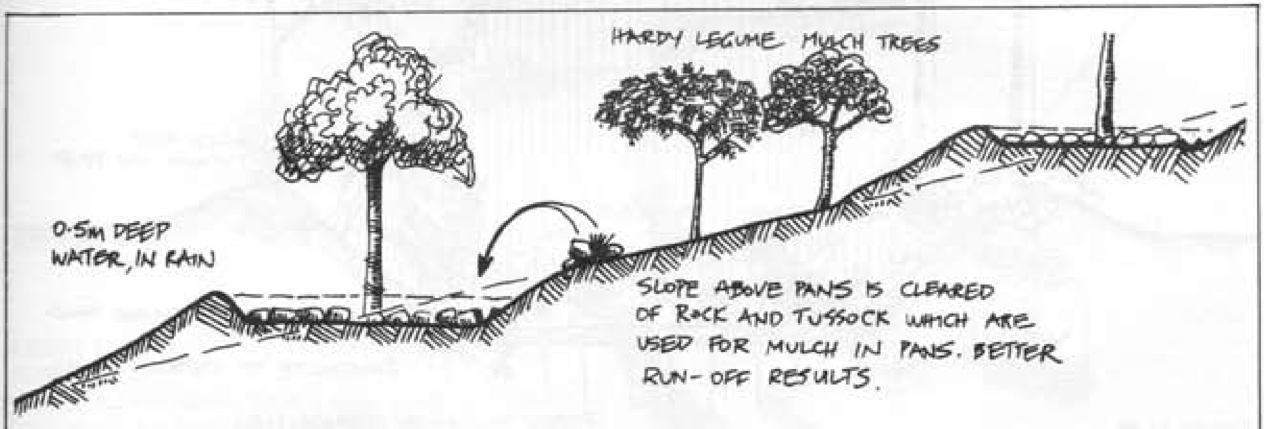


FIGURE 11.85
NET AND PAN (Elevation).

ally expand the perimeter, mulching and returning wastes as we go, and keeping the new system undamaged. Broadscale desert strategies also involve revegetating the upwind and upstream areas, and seeding ahead in readiness for favourable seasons (floods in deserts, salting, fire in grassland, etc.) All strategies are combined in **Figure 11.82**.

CREATING A FOREST IN DRYLANDS

The brush turkey *(Alechura lathami)* in Australia compacts a heap of rain-wet vegetation in an excavated pit, covers it, and allows a female to approach and lay eggs when the mound temperature is 35°C (95°F). The male attends the nest and adds material, or opens cooling vents, to incubate the eggs. A nest section (**Figure 11.83**) is in fact a large inderground compost pile, steady at about 30°C (Von Fritsch, 1975). All megapodes (big-foot) birds behave in some such way.

There are about 20 species of birds that either bury their eggs in hot volcanic sands or make compost heaps. The scrub turkey *(Megapodius freycinet)* makes a mound 12 x 5 m and the arid-area mallee fowl *(Leipoa ocellata)* a nest of 5–6 m x 1–2 m, deeply buried in sand. All of these "compost heaps" present an unusual site for tree species to locate.

In the dry savannahs of Central York Peninsula (Australia) is a rainforest clump about a mile across; at its centre is the compost-mound nest of a megapode (the scrub turkey), which is carbon-dated to about 5000 years old. The rainforest is oldest near the nest and younger at the periphery. We can speculate that the nest provided the soil nutrients for rainforest pioneers dropped by fruit pigeons on migration. In abandoned sheep stockyards near Ernabella (Central Australian desert), a leaking windmill provided some water to a 1 m deep pile of manure. In this stockyard a dense and tall "wet sclerophyll" forest structure is apparent. The desert was once forest; can it be re-forested? I believe so, and this suggests a way to try it out. The process could use the following strategies:

- Grade wide hollows (5–10 m) on contour from outwash (wadi) runnels, sloping these into the hill, and leaving 30–100 m bare (or desert) strips between each swale.
- At intervals of 10–20 m in the swales, tip a truckload of mixed chips, logs, manure, and straw or crop wastes in hollows. Cover these with 1.0–1.5 m deep of sand. Wait for rain.

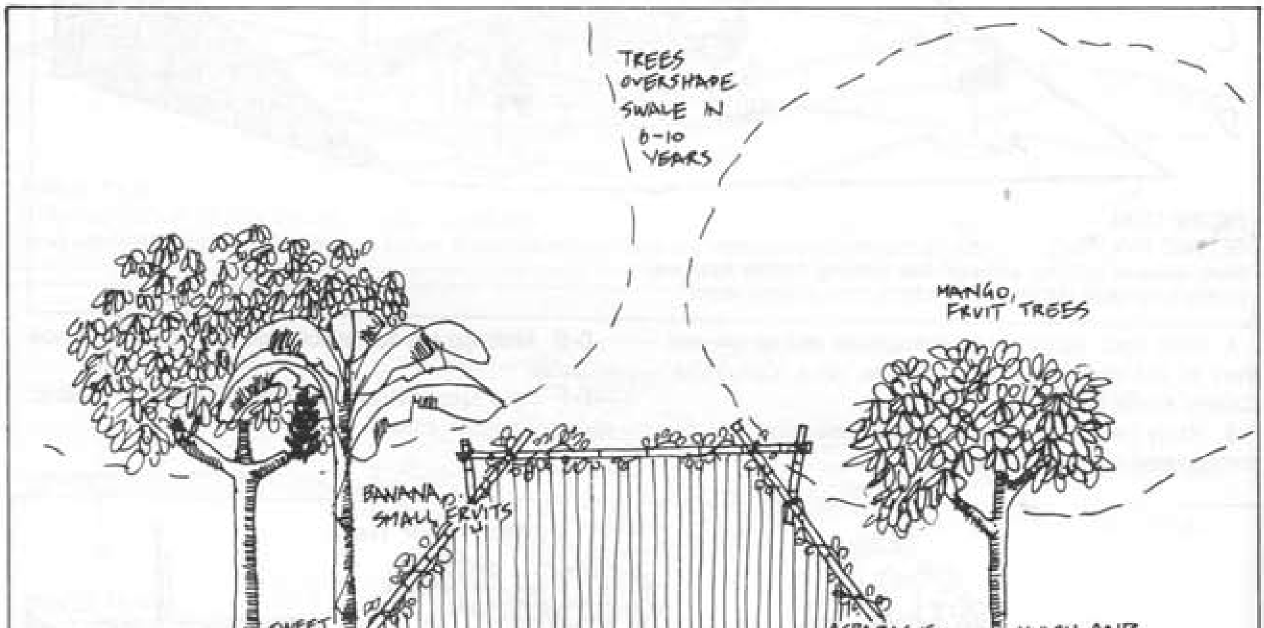


FIGURE 11.86
A developed swale, with humus and mulch, will provide water at root level for established trees (2–3 years old).

• In a nursery nearby, raise a few thousand pioneer legume and nurse crop trees in large pots and containers. All should have rich rainforest soil mixtures or inoculants.

• After a rain, when the swales are just drying out, plant the pioneer crop into the buried manure–chip areas, or around their periphery.

• When (and if) the pioneers grow, plant second–stage forest or very productive tree crop in the pioneers, again after a rain.

• If successful, slash the pioneers to let the rainforest evolve.

The inter–swale desert run–off (supposing 8–20 cm of run–off) should supply each swale with an effective 50–300 cm of water every year. The deep mulch should hold this water at tree roots, and the forest soil provide a mycelial web for roots. I see no reason why forests should not re–establish, and self–perpetuate, under such regimes.

PLANTING TREES ON HARD SOILS, SLOPES, AND MINOR SYSTEMS

High on the steeper slopes of fold mountains, small runnels feed the second and third–order streams. While the slope may be too steep for machines, and of restricted area, there are a few modest systems possible to establish trees.

One system we can characterise as "net and pan" for sheet run–off, and the other as a "boomerang pattern" for absorbing the flow from active runnels. Either can be made by hand or machine.

Figures 11.84 (plan) and **Figure 11.85** (elevation) Net and Pan. Sheet run–off absorption systems. Runnels cut at gentle slope of 1:500 (exaggerated in the diagram).

On a more irregular level, small runnels over hard ground can be blocked using a log, some large stones, and a bundle of straw or spinifex weighted down with these. The grasses trap silt, and leaves and sand soon builds a small delta of detritus into which a hardy *Acacia* or shrub will take hold. A little fertiliser often applied helps to build the system back to natural mulch. The tree roots then become our silt traps.

Figure 11.87 Runnel traps to build silt deltas on bare, hard soils. Used successfully on mined–out land and lateritic soils.

Where larger rills flow, "boomerangs" disperse and absorb flow (**Figure 11.88**).

Figure 11.59 shows various types of tree establishment techniques in difficult soils.

RECRUITMENT

Some of the large trees of the desert live for 200–4000 years. Once we have released animals (feral or domestic) that eat off seedlings—rabbits and hares are devastators, as are sheep, goats, and cattle—we may see no more signs of regeneration, and the trees that are left become less vigorous with age. Likewise, fire at increased frequency in any one area may destroy young or small plants before they seed.

Recruitment (the evolution of a new generation of plants to adult status) depends on an interaction between an adequate rainy season, fire, browsing, and a source of seed. Light fires in spring (winter–wet deserts) may generate new trees, while either cutting, browsing, or fire in early winter can kill out trees, as young shoots suffer from the colder conditions.

Seeds may germinate and plants grow, after rains, but it may need a second period of rain to establish the seedlings (about 6 weeks later). Thus, to reforest desert we need to remove or greatly reduce browsing pressure, to provide seed where none exists, to reduce autumn grazing and fire (to burn lightly in spring if necessary), and to provide some key nutrients (usually phosphates). And as well as all this, to hope for a good rainy season, or a succession of rains. All this may come together every 9–20 years, so that to keep some light stocking on deserts, we would need to have at least

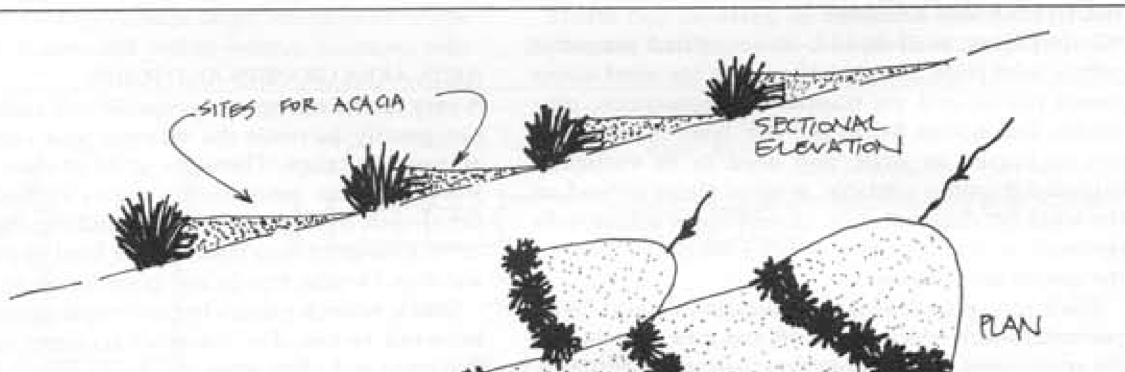


FIGURE 11.87
RUNNEL TRAPS.
Vetiver grass walls across runnels in sands spread water, hold silt for hardy shrubs and trees. Logs, straw bales, wire netting, stones in straw beds all effect the same result of building up mini–deltas of silt and leaves.

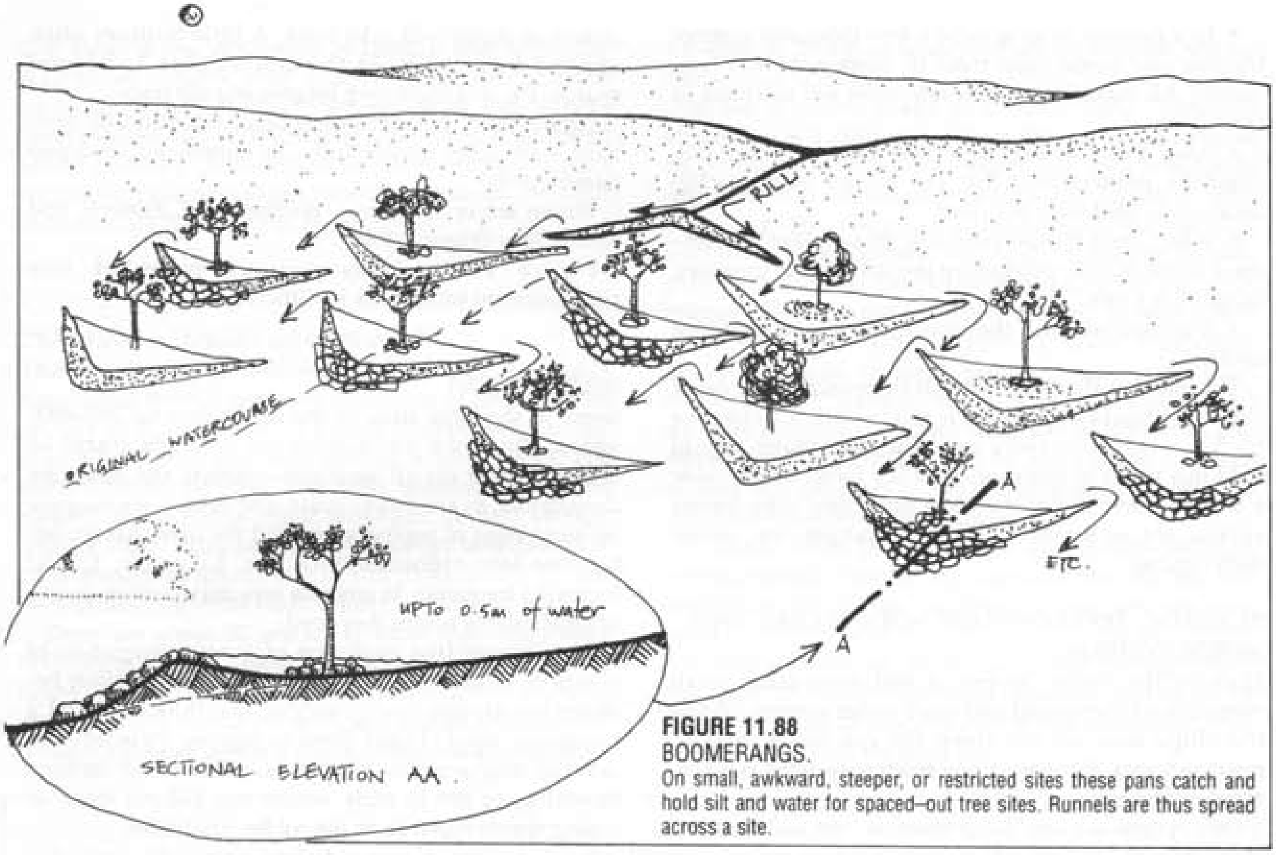


FIGURE 11.88
BOOMERANGS.
On small, awkward, steeper, or restricted sites these pans catch and hold silt and water for spaced-out tree sites. Runnels are thus spread across a site.

one-fourth (some say one-seventh) of the area free of stock at any one time, and to let the area regenerate if rains occur, perhaps assisting with a spring fire, pelleted seed, or broadscale water harvesting.

It is also possible to set up core areas of more carefully tended trees that can expand at their perimeter if seasons permit, which supply seed, and where reforestation trials (and fire trials) can be controlled.

WRAITHS AND GOLEMS

Whole plants, seed-heads, leaves, dried manurial pellets, seed pods, and dust blow with the wind across desert plains, and are trapped in depressions, pits, swales, and against fences and tree-lines. Brush fences can be buried by drift, and need to be vertically extended if sand is unstable. A set of plants depend on the wind for dispersal, seen as substantial rolling balls (golems) or dry, light, airy panicles (wraiths). Some of the species involved are:

Black roly-poly (*Bassia quinquecuspi*), a short-lived perennial shrub which breaks off and rolls, distributing the spiny seeds. A nuisance to graziers, it occurs thickly only where overgrazing occurs, and protects a wide range of soils as a defending pioneer, under which more palatable or useful species can grow. It is "noxious", of course, although what is really noxious is the state of mind which ignores its useful function. Several copperburrs (*Bassis spp*) and salt bushes try to repair scalds (areas where topsoil is gone). Most of these species have thorny seeds, and form a dense mat under rubber sandals, which must be discarded as the seeds get everywhere!

Tumbleweed (*Amaranthus albus*) is a more effete invader, a stiff wraith preferring towns and settled areas, rarely abundant. *A. viridis* (cooked as a vegetable) is also found in arid-area towns as a "weed". A mustard (*Sisymbrium officinale*), of some forage and medicinal value, is usually found only in cultivated (wheat) areas, and also spreads its dry seed stems as a wraith in dust-storms.

ARID-AREA GRASSES AND FORBS

A very careful selection of perennial and annual grasses can greatly increase the number and condition of animals on range. There are good grasses for every situation from sandseas to gilgais (natural swales developed from pockets of expanding clays). They cover a range of uses from human food to poultry and waterfowl forage, thatch, and green forage or hay.

Coarse tussock grasses become unpalatable if left unbrowsed (when dry material accumulates), or at flowering and after, when the food value is low. Thus, mown or managed swale fields are the most productive. Like all green crop, leaf material may contain dangerous levels of nitrates (dangerous to people and domestic animals) if over-manured or grown in heavily manure-polluted waters. This factor does not so much worry us if the hay is used as pit mulch for trees, but tests of garden greens should be made periodically for this factor.

Thus, I would recommend a carefully-selected sowing of some of the best grasses in plots (they can be pot-grown in the first place, and divided), and for quite specific purposes, such as to:

- Reclaim claypans and saltpans.
- Filter out silt and nitrates in diversion drains.
- Provide green hay for domestic stock.
- Give durable thatch and cane fences, mats, and screens or baskets.
- Provide bundles of seed-head for poultry, and to feed wild birds.
- Create a grassed water-way for downhill sheet flow.
- Provide a seed resource for broadscale work.

On the broadscale, there is no substitute for small, intensively managed perennial grass plots, fenced or protected to avoid overgrazing, or managed and encouraged to provide seasonal fodders. Range management is a real skill, and relies on good plant identification and management, a keen eye for animal behaviour, and a modest but sustainable stocking rate.

DESERT AQUATIC AND SWAMP SPECIES

Several aquatic and swamp plants are recorded for deserts due in part to exotic rivers that flow into deserts, and in part to run-off from ranges. There are even more species adapted to the claypans and swales (gilgais) or run-off hollows, where they grow and tolerate very hot and somewhat brackish or salty water.

There are thousands of sites in deserts where ponds and dams discharge into interior flats or flood-outs, some of which may be below sea level (as in the Dead Sea and Lake Eyre, South Australia). Thus, the desert is, in a sense, like a series of small aquatic islands, with no danger of species escaping to infest permanent streams. There are therefore ideal sites for small aquacultural assemblies and experiments.

All growing plants use up salts in growth, and some dense algae will desalinate large volumes of water, while many rushes and weeds remove dissolved salts or unwanted pollutants. It is quite feasible and sensible to set up part-enclosed and part-open natural water filtration systems to remove faecal, nitrogenous, and metallic pollutants from town water supplies, and a model of such a system is given here (**Figure 11.90**). In third-world deserts, some such benign system may greatly reduce transmissible disease, while producing useful forests and biogas materials. In addition, several aquatics provide food and wildlife shelter.

11.12
ANIMAL SYSTEMS IN ARID AREAS

Small livestock, especially chickens, quail, guinea fowl, guinea pigs, even ducks and geese all do well in deserts (however, it is often too hot for rabbits in cages). They need dense shade shelters and access to shallow clean water. They perform a multitude of tasks, especially in the reduction of insects and snails, and provide eggs and small meats not needing cool storage. On range, there are a great many desert seed and grain crops for them to forage, as well as garden and fallen fruit scraps. They will keep termites out of grain storage bins by breaking open the mud tunnels if such bins are supported on rocks.

On the wider range, highly selected and *controlled* meat and milk flocks (sheep, a *few* goats, a *few* cattle, donkeys, and camels) also thrive if they can be herded or penned in 15 or so rotated runs, allowing 2–8 years for each run to recover and re-seed. Some successful Australian sheep graziers allow 7–9 years rest per run, and never suffer the animal stress brought on by drought. It is infinitely preferable to run *small, high-value herds on copious range* than to risk the inevitable collapse of range and flocks by stressing the vegetation.

Meats can be dried in screened and shaded air cupboards, and part-salted or smoked. Strips of meat

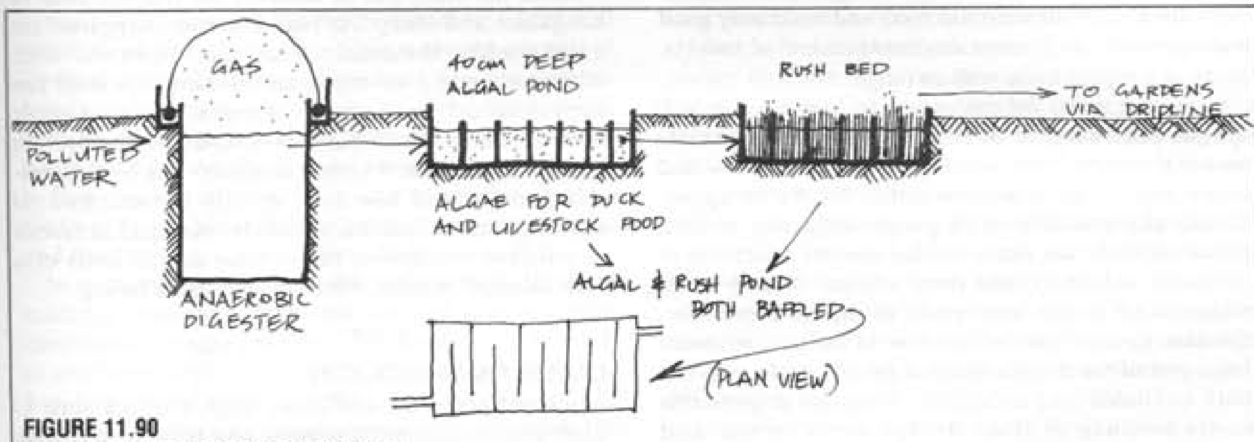


FIGURE 11.90
NATURAL WATER FILTRATION SYSTEM.
A conservative sewage system extracts gas, produces algae for adding to stock feed (or straw can be soaked in effluent and dried for stock feed), is finally filtered through a rush bed before release to gardens or forests *via* drip lines. Rushes provide bedding and craft materials.

beaten with pepper and garlic to 1 cm or less thick and 4 cm wide (as long as possible) dry very quickly and "glaze" in a few hours. This "jerky" keeps indefinitely if stored in insect-proof fine-mesh bags hung from ceilings. Complete drying can take 3–5 days.

One of the sources of animal products in deserts is managed wildlife systems. Here, we can differentiate between resident and migratory species:

• IRRUPTIVE AND NOMADIC SPECIES are large and fairly fast-moving animals such as kangaroo, antelope, and ostrich. They are able to travel long distances to areas of rain—they "smell the wind" and some wet earth and vegetation. There is also a vacuum effect in that as some move to rain, their neighbours find the old areas empty, and move towards "low stress" areas, eventually finding the new growth. Those are the herds from which many *young* animals can be culled—they die in the dry times. Healthy adults need to be preserved.

• SEDENTARY SPECIES are smaller, slower, or more specialised, adapted to drought. They will reside in an area at all times. Their "limiting factor" may be WATER HOLES (for quail and ground birds), SHADE (for large lizards and surface mammals), BURROW SITES (for small mammals and lizards), or FORAGE adapted to dry, salt, or wet areas. Thus, the strategies of small water "ramp dams" (**Figure 11.10**), rock piles and small shaded caves or cliff sites, bulldozed piles of loose earth for burrows, or key plants provided for hungry gaps may result in a local, dependable increase in those stable and staple species.

• PLAGUE SPECIES may lie in either category (rabbits, grasshoppers) but also present a potential for harvest and drying (rabbits) or conversion (grasshoppers) via a domesticated predator (chickens, guinea fowl). We tend to forget that chickens, ducks, fish, and guinea fowl will convert most insects to food and high-value manure, and we need to set up some breeding or attraction systems like the termite breeder to take advantage of this (**Figure 13.32**).

• REPTILES. Large lizards are the "fish" of the desert and are carefully harvested by Aboriginal Australians. They are a constant source of food and need only good management (and some encouragement of insects, fruits, and snails) to do well on range.

In humid areas, we can expect to find most animal species sedentary, or at least of limited and strictly seasonal movements, whereas in the desert we find many animals may become either locally or opportunistically nomadic, with people adjusting to this. However, there are many smaller species which are of necessity sedentary, and those choose "steady state" niches, such as the large grubs of moths (*Hepialidae, Cossidae, Cerambicidae*) which have in the past formed a large part of the reliable foods of people, and are in fact both palatable and nutritious. They are dependable foods because of their humid niche in the arid environment (living in the bark and roots of trees) and—because several species live as grubs for 7–8 years, and have only brief lives as adults—they are always to be found.

It is the same with frogs (*Hylidae, Leptodactylidae*) which also persist in resting states for up to 8 years, and who have fat bodies for their own nutrition, and for their predators or gatherers.

The nomadic tribes of birds and larger mammals provide a "feast and famine" resource depending on rains. At times they retire to refuges or more humid areas to survive long droughts. Such refuges may be "tabu" areas for long-term management of the species, so that they persist as food potential in the long term. These need more skilled and cooperative management, as does any herding system.

Boundaries such as fences make less sense in deserts than elsewhere because of the need of mammals to migrate, and to fall back on reserve areas in hard times. So we find that typical Aboriginal Australian diet mght contain 6–10 insect larvae, 10–12 reptile species, 6–12 birds (some taken in moult), 3–4 large migratory mammals, 9–10 smaller sedentary mammals, 5–8 frog species (mainly the females with large ovaries), the adults of some insects, some aquatic crustaceans and molluscs (3–4 species), and fish (depending on the area, 4–8 species). In all, 48–66 animal foods, and at least that many plants, including aquatics from temporary lagoons, are eaten.

SPECIES MIXES IN VEGETATION

Just as freely nomadic animal species follow mutually beneficial successions in savannahs, so very different species use the desert in a non-competitive and probably complementary way, with some opportunistic overlap. An example is given in **Table 11.5**.

Thus, both species eat dry or green forage not much appreciated by the other at that time. Almost certainly, the eating of coarse dry grasses by kangaroo enable cattle to browse more easily in wet periods (fire also helps). However, kangaroo eat very few grass species compared with cattle, who are less selective in food preference. The cattle prefer annual grasses.

Much the same sort of findings are true for euro (a kangaroo) and sheep. As both euro and kangaroo are valid yields, the total yields are improved with admixtures and good management. Kangaroo meat has been devalued, but is in fact a superior food to either beef or sheep, which have 38–42% digestible protein and saturated fats, whereas kangaroo has 58% digestible protein and low fats, mainly unsaturated. If anything, such situations should be managed in favour of efficient conversion rather than on the basis of a "pre-selected" market, which in any case is failing.

LIVESTOCK IN DROUGHT

In all arid and semi-arid areas, large livestock such as draft animals and milking cattle and buffalo are at risk in drought. If no provison for drought feeding is made, small farmers may lose their basic draft and milk animals, or sell them cheaply for slaughter. From 2–4 of

TABLE 11.5
FROM CSIRO RANGELANDS RESEARCH, BILL LOW, 1979.

CONDITION	TREE STANDS	STEPPE	DEPRESSIONS
	Acacia stands	Open forbes and grasses	Grassy depressions
A **Generally cold** (Wet season)	Kangaroo scattered in small groups of three or less.	Cattle in large groups, group close together.	Cattle in large groups.
B **Generally Dry**	Cattle scattered in small groups.	Kangaroo in large mobs near refuges.	Kangaroo in large mobs.
C **Local storms over grass depressions** (Dry season)	As for B if no local rain.	As for B if no local rain.	Kangaroo and cattle drift in groups for green crop. Some grasses eaten by kangaroo, most by cattle.

these animals are kept by most farmers, and about 17–30 can be fed on a permanent hectare of cut–and–fed forage, whereas free–range animals take from 1–5 ha to browse food in average conditions (up to 40–60 ha in drought and deserts).

Thus, 6–8 farmers need one hectare of emergency forage for drought. Such a survival forage plot needs careful planning. Essentials are:

- A frond–roofed shed for shade, where 15–30 animals can be penned. The floor should be supplied with a mulch of fronds and hard straws from sugar cane, *Pennisetum* grasses, or palms.
- Up to one hectare of perennial forage. This forage must be cut daily and fed as one–third to one–half of the ration. A forage planting layout is shown in **Figure 11.91.A**. Species include large trees such as *Inga* and carob, honey locust, *Prosopis* (for its pods), tagasaste, *Acacia*, *Glyricidia*, and *Leucaena* for coppice forage, arrowroot (*Canna*), comfrey, and *Pennisetum* for cut forage.
- A careful ground–plan of multiple cross–slope swales to catch and infiltrate run–off water in rains. This is a critical precursor to planting the forages. **Figure 11.91.B**.
- As well, all adjoining fields should be edged and wind–breaked with the same forage species, planted at 20–30 m intervals in rows throughout all other crop, on bunds, and along swales and ditches. The basic survival hectare can be cut and managed in good years, but in bad drought years, all choice or essential livestock need to be penned in or near this forage system for survival feeding. As no crops can be planted in drought, farmers and their families can tend these cattle on rotation.

In drought, cattle can be fed on chopped dry stalk material, small branches, straw, crushed cane, and even cardboard or paper *providing* they have access to a lick of molasses with a little urea added. Such licks are handily made from a petrol drum floating in a half–drum bath of molasses–urea. As the cows lick the floating drum, it revolves and picks up more molasses–urea mixture.

It is the urea–molasses mixture plus high–cellulose cheap bulk food that enables the cattle to break down some of the cellulose in the wood and straw. The rest of the ration is provided from the perennial forages. These are cut in succession and carried to the pen, and all manure and bedding is carried back to the forage fields as mulch, preferably deposited in the swales. This mulch develops cool humus soils with good water capacity over time, and the forage plants thrive on this humus.

DANGERS TO LIVESTOCK ON RANGE FOLLOWING RAINS

Both woody and ephemeral plants in drylands may concentrate any of several toxic substances as they start into new growth after rains. A partial list of these includes nitrates, oxalic acids, cyanides, sodium fluro–acetate, and poisonous alkaloids that cause infertility, liver destruction, spasm, and eventually death in wild and domestic browsers. It is the way dryland plants protect themselves from browsers when they put on new growth. The effect last from 4–6 weeks after rains, and livestock should not be released to range that contains only new growth, at least not for long periods on any one plant stand.

Mature leaf is usually non–toxic, so that the same plants that are toxic in new growth may be good browse in maturity. Cattle on such range must be very carefully herded, as any sudden shock or running will cause death. They must be allowed to move at their own pace, or left still if obviously sick. Dogs, whips, horses, and cowboy tactics generally can be fatal to livestock in these conditions, and any distant droving should be left until forages mature.

Good husbandry demands that livestock are managed in new growth periods to have a wide range of foods, some cut forage available, or some mature leaf from trees fed out.

As browsing is equivalent to severe pruning or coppicing, and wildfire removes nutrients and causes stress in regrowth plants, burnt and browsed plant stands may secrete toxins for some time after such

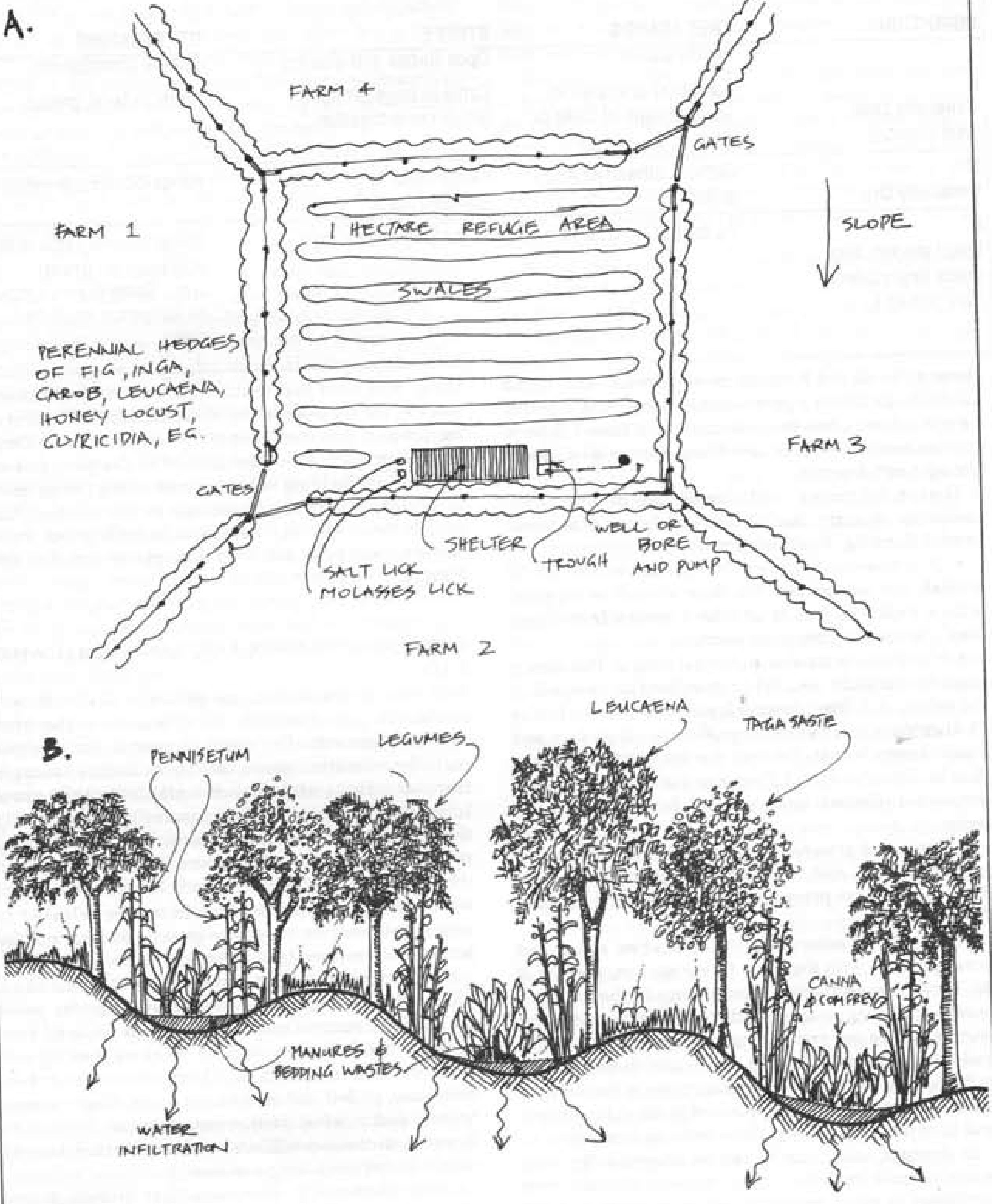


FIGURE 11.91
LAYOUT FOR DROUGHT SURVIVAL OF LIVESTOCK.
A. Thatched shelter, water, and molasses–urea lick, swale forage trees (coppiced), cheap straw or even paper feed, selected stock for survival, reserved area of 1 ha in 20 all enable small farmers to keep and milk animals alive through drought. Animals are kept quiet, bedded, not moved about.
B. Detail of reserved swale forage planting for emergency stock survival.

stresses. This plant response is linked to the other cyclic factors that cause hare numbers to sharply decline on over-browsed range. In hot deserts, fire and browsing, coppicing and firewood gathering can produce such poisonous metabolites in a wide range of both woody and ephemeral plants (Bryant, J. P, 1981, *Natural History* 90[II]).

11.13

DESERTIFICATION AND THE SALTING OF SOILS

DESERTIFICATION

Le Huerou, H.N., 1968 in *La Desertification du Sahara* (Int. Biol. Prog. Sect. C. T. Colloque Hammamet, London) gives the following causes of desertifi-cation, independently of any long-term or cyclic climatic change:

- OVERGRAZING, assisted by well-drilling to maintain higher stock numbers. Herds can not now adjust to climatic factors, and can be held at high numbers until well into drought periods.
- OVERGRAZING; stressing the vegetation beyond recovery, especially near wells.
- FUEL USE; removing timbers cut but not replanted (fencing also takes thousands of trees). Frequent burning.
- SETTLING OF NOMADS local grazing and fuel-cutting stress causes a zone of destruction, usually centred on wells; no regeneration is possible as people are no longer nomadic.
- CROPPING, often as a result of a failing herd support and in response to population increase. This extends down to 15 cm rainfall, wheras 40 cm is accepted as the lower limit for dependable cropping.
- EXTENSION OF CLEARING, following on low crop returns, thus less fallow; this greatly increases soil compaction and topsoil loss.
- EXCESSIVE WATER USE in modern times only; due in particular to deep wells or powered pumps. The upper aquifer dries up, and the local excess water use leads to salination of surface soils.
- SURFACE DRYING; the desert becomes irrevocably abandoned when oases dry up due to groundwater removal.

Damage in hills is devegetation, erosion, denudation. In eroded soils calcrete and ferricrete or silcrete is exposed, preventing productive use. Deep erosion cuts gullies in fields; dust storms do further damage. Once-stable dunes will then start to move. All these are preventable problems if early signs are heeded and if we have goodwill to the earth. Above all, desertification is a land-use, hence political, problem, and reflects the priorities of governments.

While I agree with all of the above, there are other factors affected by and related to them, and necessary to more fully understand the process of desertification. These are:

- WIND EFFECTS: Both the drying effect, wind erosion, and sand blast on plants.
- SOIL EFFECTS: Soil collapse due to deflocculation of clays; hollows and pans develop soil salting due to the above and to the development of hardpans in the B soil horizon.
- WATER EFFECTS: The increase of overland water flow due to deforestation and agricultural compaction of soils, causing gullying and salt transport to lower soils. Added to this, there is a rise in salt water tables due to deforestation.
- WETLAND SALTING: The overuse of mineral and salt-rich waters on clay-fraction soils, and over-irrigation.

These are the processes of salinisation or soil salting.

In 1928 and 1929, W. C. Lowdermilk of the United States Department of Agriculture cast a soil conservationist's eye over what archaeology had revealed of the once-grand civilisations of the Middle East, Israel, and dryland China (U.S.D.A. Bulletin #99 of 1929). He noted the patterns of abandonment of hillside settelments based on agriculture in the semi-arid lands he visited, and the eventual concentration of settlements on the valley floors, in wadis, and in oases. Many excavations in the Saharan and Thar deserts showed that catastrophic sand flows and silting had obliterated first the canals that irrigated these settlements, then the settlements themselves.

Today, thousands of abandoned towns lie buried in desert sands; people planted wheat and reaped salt. After 7,000 years of this history oft-repeated, Australia and India are on the same suicidal path. We lose 30,000-40,000 ha of arable land to salt and desertification each year. In the West Australian wheat belt, 10,000 ha of farmland is lost to salt annually, and some 260,000 ha of salted soils are now noted in croplands.

In the central Australian desert, 74% of the land (bringing in 9% of income, most of which depends on tourism) is devoted to unregulated pastoralism, producing erosion scars that are conspicious on satellite photographs. So we proceed to our own more modern extinction and elimination via an ephemeral export agriculture that will leave Australians as a "third world" people in a few more decades.

SALINITY

Salt is brought in by sea winds, as rain nucleii (CYCLIC SALT), or remains in soils and sediments from marine periods (CONNATE SALT). Cyclic salt provides plant nutrients, but can also form salt ponds or crusts if evaporated, as is evident in pools on dry, windy sea coasts. Salt is also leached from rock minerals by groundwater, which carries large loads of connate salts dissolved from old sea beds. In indisturbed country, the soils of forests have both higher salt and other mineral nutrients, and many desert trees exude or store salt in leaves, to release these salts in rain to surface soils.

Salinity is an *induced* problem. That is, it did not exist before clearing and cropping or grazing. Thus, it is theoretically preventable and reducible. Salting is usually confined to lowlands, and is not a problem in sloping upland, forested, or ungrazed regions. The acceptance that the problems of salt are man-made, although later perhaps self-generating, must dictate two early preventive policies:

1. An absolute ban on clearing or tree-cutting in any area subject to salting, which is most arid to semi-arid lands.

2. Practical field work on alternatives to decide effective local strategies.

Another observed widespread and well-attested phenomena is that salted areas actually *increase rapidly* if two or more wet seasons, with flooding, occur. This is an effect, not balanced by any *reduction* in the salted areas in subsequent dry seasons. Although it is counter-intuitive that more fresh or flood water on the land creates salted areas, it is nevertheless a fact. That is, flooded and winter-wet or boggy soil patches are those that later develop salt scalds or salt pans.

<u>Causes of Salting</u>

Broadly speaking, there are two types of salt problem. WETLAND SALTING results from the over-application of irrigation water from bores and canals to clay-fraction soils. The surplus water seals the surface soil, and pools up and evaporates, leaving a salt crust. Below this, slow percolation from rains and excess irrigation may cause the shallow soil-water table of river flood plains to rise to the root level of trees, and so kill off irrigated fruit trees and native plants. This problem can be solved by applications of gypsum, tile drains or deep drainage, and sophisticated sub-surface or tree crown-shaded drip irrigation timed to release just the minimum amount of water required, preferably at root level. However, an intractable problem is the disposal of water from the drains.

The more insidious and widespread problem of desertification and DRYLAND SALTING is not related to arid areas irrigation, but will occur anywhere we crop or graze arid areas. It is self-generating into even sub-humid areas of up to 100 cm average rainfall, and in fact anywhere that we farm country where evaporation equals or exceeds precipitation.

In 1978, Terry White (editor of the *Permaculture Journal*) and I invented the acronym S.A.L.T. (for Salt Action Liaison Team), and set out from Maryborough (Victoria) in an old Volkswagen to convene a meeting of

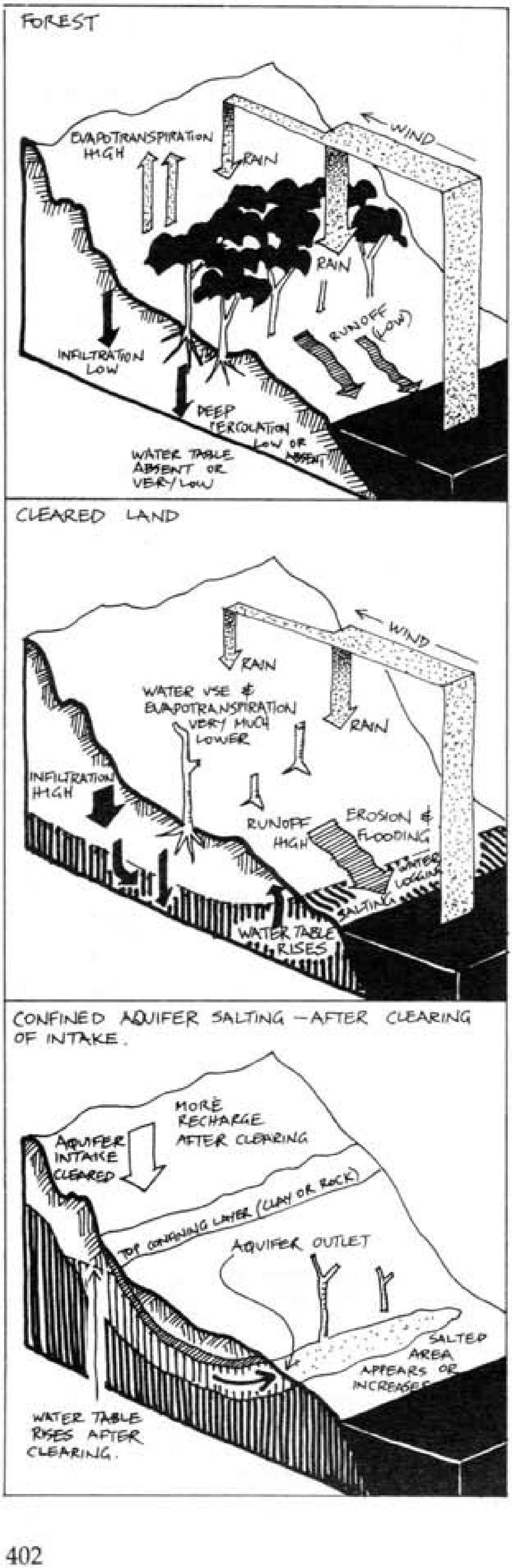


FIGURE 11.92
"GROUNDWATER RISING."
Winds bring in salt particles; very permeable cap soils infiltrate rain, and if forest is removed, this water causes salted groundwater to rise at the foot of slopes. Often, cap soils are volcanic, slope soils of shale or mudstones (Victoria, Australia). Trees can be replanted on cap soils to stabilise this situation, but lower soils may have collapsed.

farmers (who were losing their land), churchmen (who were losing their congregations), and local government representatives (who were losing their towns and rate incomes). Subsequently, strong action teams formed, on Terry White's initiative, and grants were raised to tackle the Loddon–Campaspe area in Victoria by tree planting.

Our reasoning was based on the premise that salt rises up from deep soil reserves due to tree removal, and that permanent trees pump out these rising groundwaters, keeping the salt water table below damage levels. This is the GROUNDWATER RISING theory, and is widely accepted as the cause of non-irrigation salting in Victoria, where very large areas of country freely absorb rainfall, and where water tables are close to the surface (2–10 m down). **Figure 11.92.**

By planting trees, therefore, we would "pump down" the water and salt, and enable cropping and pastoralism to continue. We had all, I think, accepted this model of dryland salting: cut the trees, and the salt rises; plant trees, and it goes down again. This model presumes that deep waters in the soils are free to rise to the surface by infiltration, followed by evaporation and by capillary action, and it takes no account of the effects of farming and pastoralism *on the soil itself*.

However, late in 1985 I visited West Australia and took the opportunity to speak to many farmers about the W.I.S.A.L.T. scheme (see **Box**), based on a premise not of deforestation alone, but of SOIL COLLAPSE due to two influences. Soil collapse is primarily due to clearing, cultivation, and hoofed animal compaction, and secondarily to swamping of these compacted and damaged soils by surface (overland) flow of rainwater carrying small quantities of salt falling as cloud or raindrop nucleii. In addition, salt is released from the collapsing soils and from the heavier concentration of surface salts which are found under forests and leached when these are cleared for cropland.

Salt (as sodium chloride) releases chloride ions, which are rapidly washed away or escape to air, and sodium ions, which bind on to any clay crumb particles and displace calcium ions, causing a rapid disassociation of the clay crumb structure of the soil if sodium exceeds 15% (known to soil scientists as DEFLOCCULATION). As a result, not only the soil *surface* is sealed, but deeper clay particles and minerals displaced by the sodium migrate, and cement the subsoil into a hydrophobic (water-repellent) block of rock-like consistency, a cement without the air spaces of true soil. This *seals off the surface soil above* and creates an ever-increasing swamping by overland water flow (cascade effect), worsening the initial problems. Rapid deep infiltration is blocked, and the surface soils flood easily in rain (**Figure 11.93**).

At the same time, hot winds begin to take effect on clearings over 500 ha in extent, or more than 5 square kilometres across, drying out crop soils and vegetation as yet unaffected by desertification. Thus, newly cleared land becomes degraded in about 20 years, whereas the older farms (clearings in the bush) can take 100–150 years to develop soil and salt problems.

Strong winds, often as a downdraft wind in advance of (dry or wet) thunderstorms, create dust storms that deposit very fine topsoil deposits on high plateaus, on gravel ridges, in the lee of hills, and of course in towns. In Alice Springs, this loess covers the hill graves of the pioneers buried before 1966 to a depth of 1–2 m. Since 1966, soil pitting and grassland growth has stilled the dust in that area, mainly due to the need for a reliably open airport! At the same time, grazing was excluded or rigorously controlled to prevent a recurrence of the dust problem.

The silty dust from wind storms can now trickle or work down into the once-open rock crevices of hills, and thus seal off or reduce the effectiveness of the old water intake crevices that feed underground aquifers, hence springs and rivers. This again exacerbates the effects of overland flow, soil erosion by floods, deflocculation, and soil collapse. Now we have two effects—damaged intake areas and sealed subsoils—that will cause a cascade of run-off rainwater over and through surface soils, while the subsoil remains *dry*. The cemented subsoil also seals off the soil from the parent rock below, created a perched water table in rains.

An aerated soil of 1 m deep in an untouched state can contain 8–20% humus, 10–40% clay, and can be as much as 40–60% air space (Leeper, 1980). Once the soil humus

W.I.S.A.L.T. is an acronym for WHITTINGTON INTERCEPTOR SALT-AFFECTED LAND TREATMENT SOCIETY, founded in March 1978. Harry Whittington of Brookton, West Australia, has evolved (from practical field work) the soil collapse explanation of desertification. This society now has 1,100 farmer-members, and trains consultants and contractors to build interceptor banks correctly. As great care is taken in the size, spacing, grading, and construction of interceptor banks, a period of training with the W.I.S.A.L.T. people is necessary for both farmers and contractors. Even the bulldozers are modified to create a 1 metre blade drop for delving the ditches and ramming the banks to seal them. There is a vast amount of effective (and ineffective) land-forming to be assessed in the wheat belts of West Australia, and a lot of results to hand.

Literature and information is available from The Secretary, Box 154, Quairading, West Australia 6383. Many members can supply data supporting both the explanations and remedial earthworks needed to hold back, or reverse, desertification on farms. They fully convinced me (I peered into miles of canals and ditches) that their theories were correct; certainly their land therapy is working. I believe their efforts are worthy of international recognition. Harry Whittington is yet another unrecognised "great Australian" with a love of land and good husbandry.

My thanks go to Lex Langridge for transport, Gavin Drew of Beermullah, James Gardener of Bungulla, Mac Forsythe of Kellerberrin, Laurie Anderson of Quairading, and of course Harry Whittington of Brookton for explaining their approach to land reclamation. Many thanks also to my friend Terry White in Victoria for his constant inspiration and persistence.

is removed by fire, cropping, and over–grazing, the clay deflocculates to fill the air spaces, and the crumb structure compacts to a cemented surface, or to residual fine sand and dust (which blows away). Little soil humus remains. 1 m depth of soil can by these effects be compressed or eroded into a layer only 10–20 cm or so thick, overlying a cemented "B" horizon of concrete–like consistency.

This is the process of soil collapse. Of course, any salt in that original soil, and previously dispersed through the whole open soil layer, is now concentrated to make a very salty zone around the collapsed area. Desertification has arrived *by a process of soil collapse*, a different but complementary effect from that of groundwater rising as it occurs in Victoria. Tree planting in such conditions will fail to reverse the process as trees cannot long survive.

During the process of soil collapse, crops, pastures, and isolated trees suffer. The collapse produces *anaerobic soils* (without air spaces), and humus decay then becomes subject to anaerobic bacteria producing ethylene, methane, and sulphurous smells, typical of all waterlogged and compacted soils. This is a wide-spread and easily observable phenomenon on our farms and wheat belts. Mottled and waterlogged soils, often with iron stone layers or iron "buckshot" concretions, are found at the base of slopes on many wheat farms, just above a salted area of dying trees and shallow salt pans.

The collapsed soil areas sink 1–2 m, and (in valleys) produce sunken salt pan areas. These, in turn, cause further peripheral soil collapse due to edge swamping and salting, and may develop into extensive winter salt lakes, with a greater and greater collapse effect on their adjacent soils. Salt is also washed downstream and into dams to refer the problem elsewhere. All these processes rapidly become self–generating.

The natural process is believed to take 10,000 or more years of alternate wet and dry seasons, before this argillic (clay) skin, plus iron and silica cements, builds up a layer impermeable to roots and water. The deforestation of soils and the subsequent solubility of clay due to mobile salt can speed up the natural process considerably. While such effects are good for water crops (rice, taro) in humid areas, they become lethal for

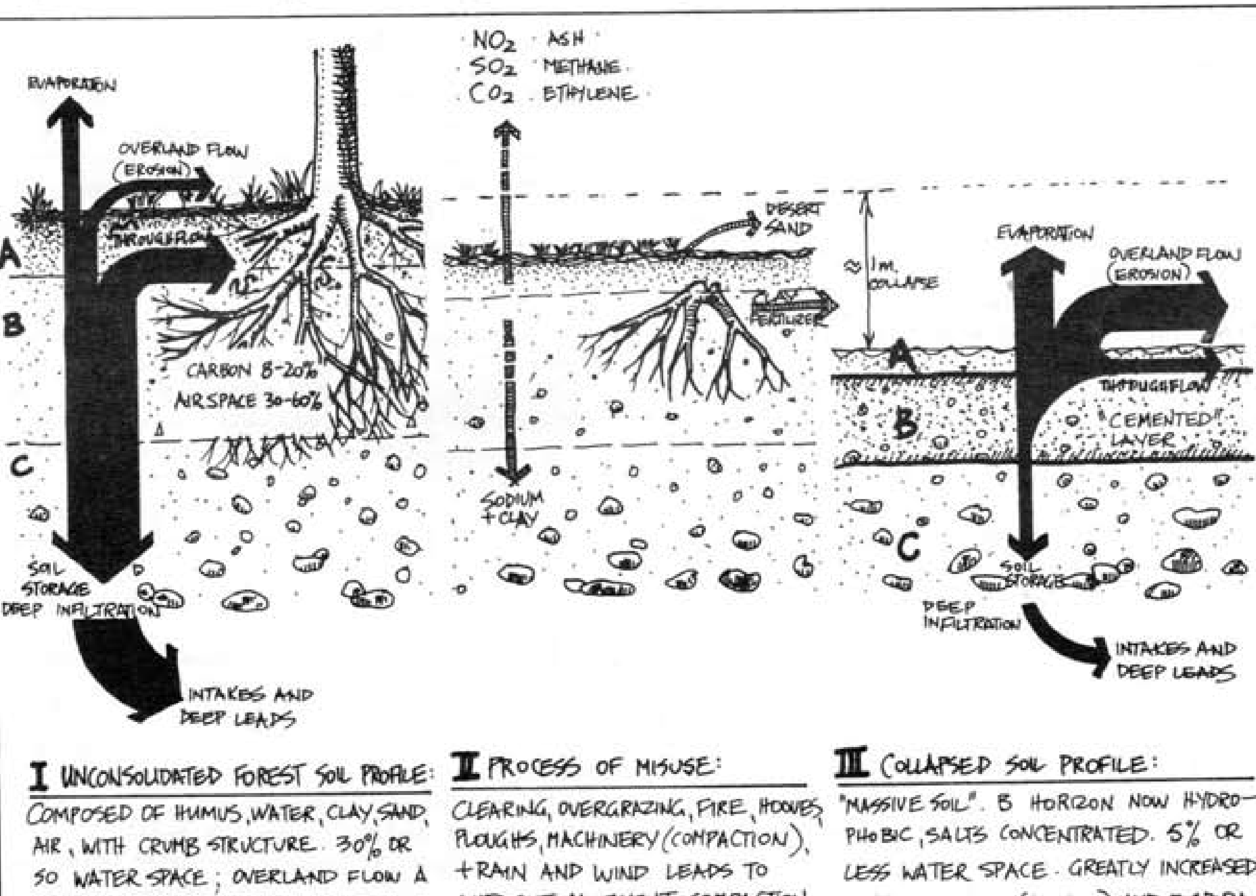


FIGURE 11.93
PROCESS OF SOIL COLLAPSE.
After misuse, sodium ions displace calcium, clays deflocculate and soil pore spaces fill; soil collapses to a cemented hardpan which seals off the subsoil. It is now almost impossible to plant trees without a long rehabilitation process, interceptor banks, and humus development (West Australian soils).

dryland crop.

Foth (1984) notes that deep drainage plus gypsum or (more slowly) sulphur will restore acidic soils, but that the leaching out of salts that follows may effect stream health. Interceptor banks leading to creek or river beds effectively drain and permit leaching of the salted soils. Where the pH is more than 8.5, gypsum is also indicated to assist sodium removal.

Wherever we irrigate with saline waters, we must flush salt out or drain the soils thoroughly, but in the end one wonders if cropping on such soils is inevitably risky, and if diversion to energy production via tree crops, or tree crop and modest animal grazing is not a better use of drylands. In particular, flood irrigation of furrowed fields can result in a 60% evaporative water loss, and a two- to seven-fold increase in salt concentration. Salt in ridge and furrow systems of flood (furrow) irrigation will increase on the ridges where less flushing occurs. Thus, ideally we should flood the ridges by creating beds with raised edges, and flush the salt *down* to the furrows.

Leeper (1982) notes the reduced ability of cropped soils to infiltrate rainwater; in adjoining fields, up to 30 cm can be absorbed by uncropped soils over a period of 5 hours, while in identical cropped soil, only 5–16 cm are absorbed. He notes that these differences are greater than those between different soil types. Wheat cropping is therefore of itself a cause of increased overland flow, and the subsequent flooding of lower soil profiles, as is soil compaction by overgrazing, and the use of heavy or fast farm machinery.

As for pore space, the specific gravity (S.G.) of an open soil is from 1.0–1.6 (equal to or greater than an equal volume of water). The S.G. of soil mineral components is 2.6–3.2. Thus, the average air pore space in the total volume is 50% or more (generally 40–60%). In a flooded soil, all but a few of these pores are water-filled. If that water also contains salts, and deflocculation occurs, the soil crumb structure quickly breaks down, and pores are clogged with dispersed silty particles. In wheat lands, only 12% of the soil may be well-structured (crumbs of 0.25 to 2 mm), while in free-draining uncleared soils, 92% of the soil is composed of such particles.

Thus, it is clear that the structure of soils under dryland cultivation can in truth break down, and that almost all the soil pore space disappears (even though cropping is still possible at 12% crumb structure).

A major factor in soil crumb formation is the presence of polysaccharides (long-chain sugars) and gels produced by humus; this humic material is critical to good soil structure. The widespread practice of burning dryland grasses and wheat stubble further reduces the soil humus. Fire can actually bake surface soils so that they form fine dusts which blow or wash away. Humus as green crop added to neutral or alkaline soils will, however, restore crumb structure if salt water deflocculation can be stopped.

In collapsed soils, tree and plant roots face two inseparable problems; even if not flooded, the reduced pore spaces contain little air, but in rains, soil carbon dioxide levels (waste gases from root respiration) may reach the level of 5% (it is 1% in healthy soils, 0.03% in air). This is a lethal level for plant root growth. As well, sulphur-concentrating (anaerobic) bacteria produce methane and sulphur dioxide (marsh grass) as a result of the decay of humus in these anaerobic conditions.

Finally, the weakened plant roots are subject to rapid drought effect by surface evaporation, and face osmotic stress from the salt water in the soil. A point comes where soil salts prevent water uptake by roots. No wonder we are losing trees and crops throughout the drylands!

It is now obvious that to plant trees in soils already in process of collapse is futile. We need to stop the process of soil collapse itself, and it is here that the W.I.S.A.L.T. group have evolved what I believe to be a unique and successful West Australian hill farm solution to soil collapse and desertification.

Interceptor Banks

In earlier times, shallow (0.5 m deep) CONTOUR BANKS were built to stop soil losses on slopes. Even gentle slopes (3° or less) lose soil in rain as farmers remove tree cover. Because lower slopes get more water, as flow-down, soil erosion is not much less on plains than it is on hill slopes of 10° or so. Contour banks did not, however, have a profound effect on wind erosion, gully formation, tree death, or soil collapse by flooding; indeed, salt eventually causes contour banks to collapse, and run-off floods over them in heavy rains.

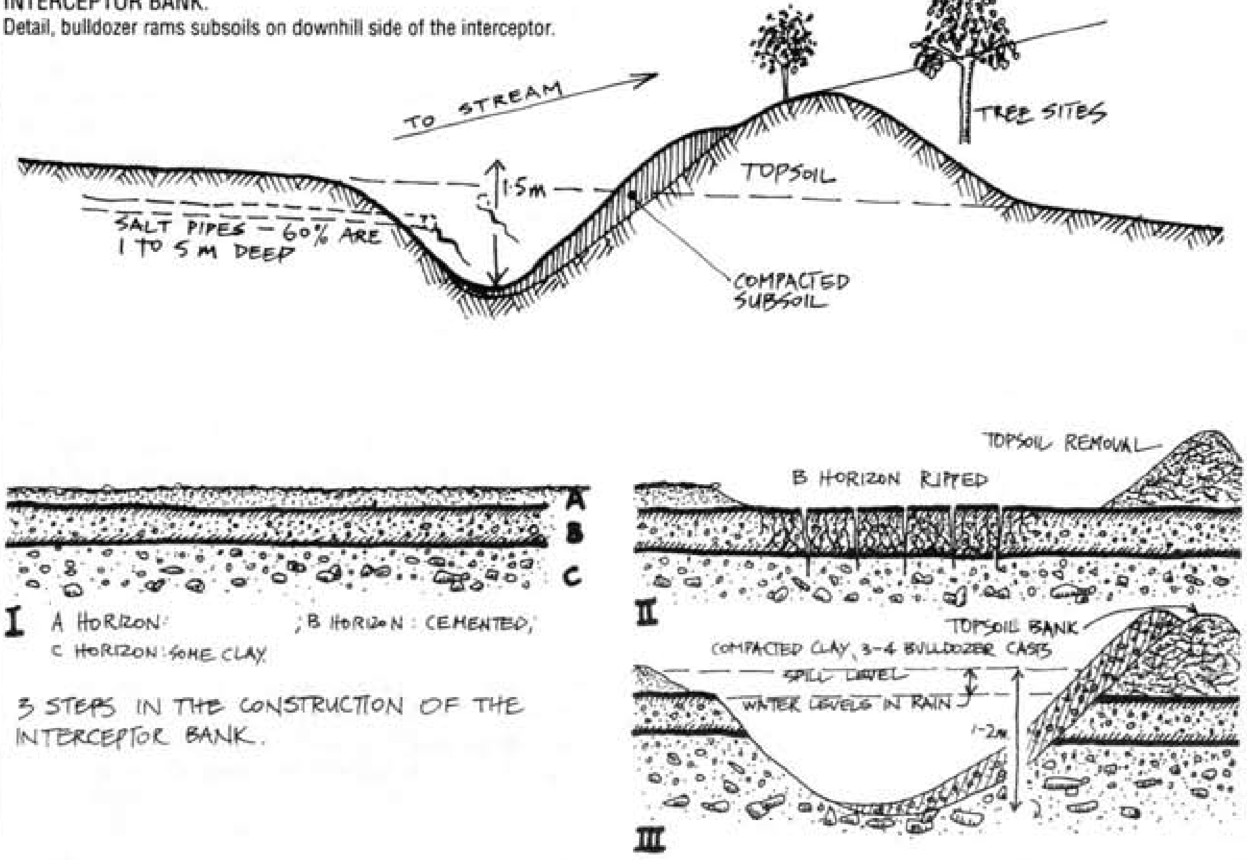
Although our salt problems first appear in low flat areas and valleys, the water that causes the problem cascades downslope. The W.I.S.A.L.T. approach is to first tackle the problem at its source—the hill tops. Starting about 1–3 m below the ridgelines and plateaus, a deep (2 m) and wide (3–5 m) ditch is bull-dozed up on contour. Care is taken to first push off any topsoil, to dig 1–2 m down with a bulldozer blade to break up the concreted subsoil (it is often necessary to also rip), and then to compact this clayey and stony layer by ramming it firmly against the *downhill* bank of the ditch. Ditch and bank together are called an INTERCEPTOR BANK (**Figure 11.94**).

If the downslope bank is effectively sealed, all high run-off or overland flow stops at the ditch, as does the slower seepage or throughflow of the topsoil, which perches on top of the compacted "B" horizon as a general seepage line. No flooding of downslope soil results, and further soil collapse ceases. While the higher banks are made on the level as swales, downslope banks slope at grades of 1:3000 to natural stream beds, and thus both salted and fresh water are carried to sea in streams. Within 2–3 years, the strips between the banks commence to regenerate grasses, and dying trees regain health.

More interceptor banks, still on contour, are now built every 3 m (vertical height) downhill. On slopes of 10–15° or more, these form a continuous series of ditches (piped or stone-filled for machinery crossings at intervals) from ridge to foothills, They immediately stop overland flow and seepage, and hold all fresh water after rains (Figure 11.95). Their spacing is carefully calculated to *totally intercept* any water that would otherwise flow or seep downhill. As slopes lessen to 5° or less, the spacing is altered to a maximum of 300 m between ditches, and the ditches are made so as to end on (or rather start at) and spill into natural waterways, carrying off water flow surplus to the capacity of the ditch itself. Wherever such ditches leak or overflow, areas of collapsed soil and grass death are visible, but grasses re–colonise salt pans wherever uphill water is fully intercepted.

Open hill intake areas, even if damaged, still feed deeper streams by slow infiltration into old sand seams, permeable rock strata, or sandy soils trapped below the "B" soil horizon. These shallow aquifers can cause lower slope flooding, and wherever they are located, they too

FIGURE 11.94
INTERCEPTOR BANK.
Detail, bulldozer rams subsoils on downhill side of the interceptor.



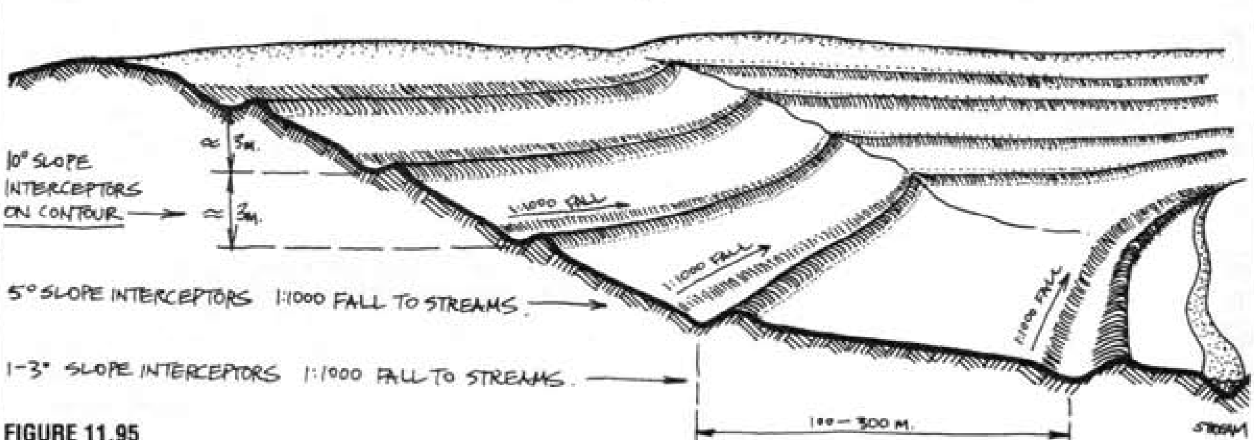


FIGURE 11.95
CONTINUOUS INTERCEPTOR BANKS.
Spacing of interceptors on hills and plains; all spill to natural streams. Upper banks are swales at 1–3 m vertical spacing; lower banks cut salt "pipes" to 1.5 m down; soils blocks are isolated from "cascade" effects of salt in topsoil, pipes. Crops on soil blocks, trees on downslope banks of interceptors are now possible.

are dug out to base and clay-filled or blocked by vertical plastic barriers so that their water (at head) also flows into the interceptor ditches, and thence to streams, or from uphill ditch areas via pipes to dams or storages. Water is then available to stock and wildlife as waterholes where no such source of freshwater at head previously existed. Most seepage flows occur at less than 2 m depth, but deep sand seams to 6 m depth can be dug out by back-hoe and blocked by vertical plastic sheets buried in a clay backfill. Sand seams are detected by backhoe digging, radar from satellite, or locally by dowsing. When banks are constructed, as many of these deeper seepages as possible are blocked, lessening surface seepage lower in the catchment where the shallow aquifers discharge. In effect, seepage comes to a standstill.

Deep sands or old dunes do not collapse (they are, after all, up to 93% silica sand grains) but instead act as freshwater "tanks", sitting on the landscape and seeping slowly from their base. Interceptor drains downslope from such sandy areas remain water-filled with fresh water as canals all year, and are very attractive to waterfowl, small fish, and water plants. The interceptor banks cut off freshwater seepage water from these, and also from salt lakes or dams that lie above valley farms, directing it harmlessly to streams and thus preventing the winter flooding of surface soils. Salt lakes can have early wet-season floods diverted around them, and only later fresh run-off waters are diverted to fill them. In this way they become suited to fish and waterfowl.

The beneficial effects of interceptor banks are rapidly evident downslope. Wind erosion and flooding in rains ceases on construction. Crops regain health, fertilisers are no longer washed away, dying trees recover, and new trees can establish (they often appear on the banks soon after construction). Long-term soil recovery and gully elimination can, however, take up to 10 years of careful husbandry. Tree-lines 5–8 trees wide *below* each bank stops the drying-out effect of the desert winds, and eliminates wind erosion on the fields. The uphill side of ditches are left free of trees in case maintenance is needed.

I cannot overstress the importance, to every country, of this well-tested present approach to soil and water conservation, and the consequent reversal of salt scalds, gullies, and desertification. In hard cash terms, the farmers I spoke with in West Australia estimate that in 5–7 years, cash returns from increased livestock and crop yields pay for all the earthwork.

We could all help by investing in such beneficial and remedial work that salt-afflicted farmers themselves may not be able to afford. We might also insist that our government co-invests in this work, as much more land has been lost to salt than we can ever replace, If we are ever to get our economic priorities right, this aid to preventing salt must take precedence over thoughtless investments in the stock market and real estate fields that destroy real wealth merely to make money. We must relieve the pressure on the land that caused the collapse of our rural soils in the first place.

Groundwater Rising

Dryland salting is attributed to rising groundwaters derived from deforested aquifers in Victoria; some of the deep sand aquifers sampled contained very salty water (30,000–42,000 ppm), rich in iron, and acidic. Where these eventually surface, 180,000 ppm salt is possible in lagoons or creek seepages. Alkaline limestone aquifers may have less sodium salt ions (960–3000 ppm) and can supply domestic or stock water. In many areas of Victoria and inland Australia, water tables are in any case high, and if these deep leads discharge into them, salt is not far below the surface. Here, the answer is to restore forests to the hills and plains.

While tile drains and pumping can reduce wetland salting, dryland salting via aquifer discharge is too large a problem to solve by mechanical pumping. It is clearly evident that country under forest (in the same areas) is not salted; it is the agricultural clearing and wood-chipping, or net forest loss, that creates salt deserts.

In Victoria, interceptor banks have not been widely trialled, and soil collapse is not invoked as an explanation for the broadscale salt seepages that are obvious above the sealed or cemented "B" horizons of the soils, and that create sunken off-stream salt lakes at the foot of slopes.

In drylands, any rise in water table or compaction of soil can be taken as a warning of salting danger. Surface indicators are brownish patches of sea barley grass*(Hordeum maritimum)* and buckthorn plantain *(Plantago cornopus)*. Crops lose vigor, and the subsoil is saturated and anaerobic.

At a groundwater level of 1.8 m of so, capillary soil action takes over, and surface evaporation of soil water creates salt crusts (efflorescences). Salted areas then spread uphill, rushes evolve *(Juncus)*, and bare soil areas increase. In West Australia, the uphill spread is attributed to the damming of groundwater flow by lower areas of collapsed soils. Wet years exacerbate the problem, which does not necessarily recede in dry years.

It is obvious that evergreen trees, transpiring more water than crops, keep the water table down and permit better rain infiltration and soil pore space. At the same time, forests in drylands excrete salts which accumulate in surface soils, and it is these salts that are further concentrated by soil collapse. In the West Australian soils, over granites and gneissic areas, salt reserves to 20 m deep are 3,400 to 19,000 t/ha, and most of this lies below 2 m, or below the forest root zone. In Victoria, basalt cap soils are good infiltration areas.

Rainfall contains 5–10 ppm salt, derived from the 33,000 ppm of seawater. Salt content falls off inland, and rain deposits 27–150 kg/ha/year in Victoria. It would take 100,000 years at 50 kg/ha to build up the soil salt levels noted for West Australia. Salt loss by stream flow (running to sea) about equals that coming in as rain (hence "cyclic" salt), but where areas are farmed, salt levels in streams can be 20 times higher as connate salt is mobilized by groundwaters and soil collapse.

In West Australia, only 0.7% of original tree cover remains, in South Australia 3%, in Victoria 13%, and in Ethiopia 4%. All suffer increased stream and groundwater salting, raised water tables, and increased artesian pressures from deep salt leads, risking surface salt seepages. It is therefore a critical strategy to forbid further clearing on any land (South Australia has done so), to trial interceptor banks, and to revegetate upland or intake areas with trees.

To sum up the evidence on dryland salting:

• Soil collapse can occur in clay-fraction soils, causing waterlogging, gullying, and crop death from compaction and anaerobic soil conditions.

• In deforested areas with large areas of water intake formed of permeable soils and sheltered rock, salty groundwaters can rise by flood infiltration, as it does in over-irrigated areas.

• Excess soil water from the latter effect is most effectively removed by trees (versus crop or fallow).

• The reduction or elimination of overland flow by interception banks enables collapsed soils to recover, and that until this is done, trees will not survive.

There is every reason, therefore, *to examine the local situation* before recommending either tree planting or interceptor banks; the latter are appropriate in soils with obvious cemented "B" horizons and obvious rainy-reason waterlogging, but where both the "B" horizon and any underlying strata can be *quite dry*. Tree planting is likely to be effective in areas where deep permeable surface soils or strata are found, where no cemented sub-surface layer occurs, and then only where groundwaters have not reached to 2 m of the surface.

Until interception banks have been made in collapsed soils, tree death will occur and new trees live only until they are a year or two into growth; after that, they waterlog and die.

The best way to discover what local problems are occuring is by digging back-hoe pits and observing how they fill—whether water wells up from deep seepages, or trickles down from shallow seepage above the "B" horizon. This decides corrective strategies (trees alone, or interceptor banks plus trees).

Swales to infiltrate rain water are appropriate only if *trees are planted along them* to reduce the net infiltration above deep clay layers. Swales are, however, valuable aids to tree crops and concentrate fresh water at tree roots.

Finally, there is no doubt that any nation which permits over-grazing or cropping which reduces tree cover in areas where precipitation is exceeded by evaporation will, in a few short decades, lose its drylands to deserts and salt. It is long past time to legislate and to divert public monies to both stop and if possible reverse these effects world-wide.

Cautious Approaches

Given the multiple interactions possible between salts, evaporation, soils, slopes, drainage, and land use, and given that problems may not show up for 100 years or more, designers must always be willing to follow a sequence of cautious approaches to ensure the permanent use of drylands. I believe these to be as follows:

• To try a great variety of small systems of earthworks and land use practices on only one slope or soil type.

• To then monitor such factors as infiltration, evaporation, salinity changes, and crop health over a few years.

• To cautiously extend systems that do not show any salt increase in soils over the short term.

• Above all, to store no run-off where tree roots cannot remove the water, or to tree crown shade the storage, unless it is subsurface storage in sand basins or sand dams.

• Where groundwater tables are shallow, concentrate on *lessening* infiltration by floodwater DIVERSION to streams and floodways.

• Where soils are free-draining, concentrate on *increasing* local infiltration by swales to increase tree cover.

• Where gardens are to be made, use ridge trickle irrigation in dry periods, and if possible allow flood-waters to flush out furrows of accumulated salts in rain.

• To favour roof tanks and surface swales rather than wells or bores, which lower total aquifer resources and create local excesses.

• In particular, use back-hoe or deep pit samples to establish the conditions of drainage locally, and then proceed to strategies based on the local conditions (diversion, interception, swale infiltration, and crop type).

• Make every attempt to assess potential yields before doing any of these things. Any yield we can *manage* is preferable to one we *create*; it may be easier for us to manage and increase natural yields (e.g. the saiga antelope in steppe, the kangaroo in Australia, or the 140 species of large animals in Africa), whether animal or plant, than it is to impose an exotic crop or animal species on a fragile environment.

• Observe every case where yields are naturally high; these conditions may indicate a safe way to increase yields at least risk (e.g. patches of forest where dunes converge on a sloping pavement, or large trees fringing a dry river sand-bed). Such conditions are likely to have withstood the tests of time.

Having examined (preferably by digging pits or inserting piezometers in key areas) just what local salting effects are in process, farmers and designers can choose from a set of strategies (or even use all of them if product increase justifies the expense). These are:

1. Swales at high levels to establish trees, which reduce net infiltration.

2. Interceptor drains leading to natural waterways at midslope and on lowlands.

3. Where intake areas can be identified, intensive planting of trees which use plentiful soil water (e.g.

Eucalyptus camaldulensis, E. sideroxylon, E. wandoo [drylands], *E, globulus* [cool wetlands]), and *Casuarina cunninghamii* plus *E. camaldulensis* to use surplus sewage or other waste water in lowlands. The choice of species needs local trials. Natural tea–tree vegetation in swampy valleys (*Leptospermum, Melaluca, Banksia*) are killed by salt, but are re–established if uphill effects are controlled.

4. Subsurface drains ending in natural waterways or interceptor drains are worthwhile where the crop is of high value.

5. Bores and pumps to lower water tables in irrigation areas should be looked on as a last resort, and may be supplanted by trees if headwater infiltration can be controlled.

Whatever the methods used, salt levels will rise in streams as soils are flushed out, and once we have salted lands, fresh water for settlements may need to be supplied by rainwater tanks and hill sand storage dams until streams regain health—and this could take decades.

Interceptor banks and drains leave more land open for cropping, but trees have a very definite value over recharge areas, and as a valuable energy crop in their own right. It is cheaper, however, to reclaim salted lands than it is to clear new country for short–term cropping, so extending the problem. Above all, we should continue to study the chain of effects that cause deserts, and design to eliminate each of these in turn.

Additional Methods of Salinity Control:

- Changes from shallow–rooted annual or pasture crops to forage tree crops and fuel–wood supply is a long–term but currently profitable land–use shift to sustainable culture. Fallow or bare–soil cultivation, stubble burning, and shallow–rooted crop all exacerbate the problem.
- Eliminating leaky channels for impermeable pipes, using sophisticated irrigation at root level, and closely monitoring irrigation water to minimum levels are all essentials to reduce wasteful water use and excess infiltration. In some areas of Australia, only 26% of channel waters actually reach farm, and on–farm use may waste 60% or more of the remainder (e.g. in extensive spray or flood irrigation without close supervision). Piping eliminates land lost to open channels, sand drift problems, and preserves water quality.
- Salt–tolerant plants can be more used to supplant affected crop. Saltbushes *(Atriplex), Acacias, Prosopis, Puccinella* grass, bluebush *(Maireana spp.)*, samphire *(Crithmum, Salicornia)*, tall wheat grass *(Agropyrum)*, Wimmera rye grass *(Lolium rigidum)*, and a variety of seashore and inland plants will thrive in soil of more than 0.4% sodium chloride. However, emphasis on salt–tolerance will simply delay investigation into basic causes and treatment, and so has not been emphasised herein.
- Above all, careful assessment of local factors, a return to more natural yields, and a *true* economic assessment of the costs of farming versus aid to gardeners will almost certainly reveal the benefits of closing down most marginal agriculture, and returning the area to a natural managed system of sustainable yield.

11.14
COLD AND MONTANE DESERTS

In the arid plateau and high valley interiors of continents, are very extensive desert areas with great extremes of temperature, extremely hot clear–sky day radiation, and very cold icy nights. Woolly plants and woolly animals survive these conditions, and silvery hairs protect them from heat and cold. Very solid houses are needed, and fuel is a special problem, as all plants grow relatively slowly. Willows, birch, poplars, junipers, and fast–growing or tuberous summer plants are called for. Damp stream areas grow good tree crops. Snow at high altitudes will melt directly to vapour, to blow away on winds, so it is essential to swale for snow–melt, and to grow trees as snow traps in or near these swales. Even fences help to retain snow for meltwater in streams.

Stone piles and mulch preserve a moderate air layer over plant roots, and hardy grains will grow on small fields, as will root crop for winter storage. Rocky soils are good growing sites, and rocks help preserve ground warmth and moisture. Some good fish species occupy lakes and streams, as do beaver and large aquatic rodents. Chickens and guinea pigs survive, the latter in houses or in a small room near the kitchen to keep them warm. Trombe walls, well–sealed double entries, glazing over massive internal courtyards, and earth sheltering are all ideal house features, together with massive fire–flue walls and efficient stick–wood cookers.

Clothing needs dry, airy, absorbent linings and wind–excluding waterproof exteriors (furs inside out) to be comfortable, and radiation burn must be guarded against by visors or broad hats, dark glasses or snow (slit) glasses.

When we move to cold deserts and arid montane climates, the vegetation changes from dry–dedicious to winter deciduous. Sugars are stored in saps rather than pods, and evergreens are conifers rather than *Acacias*. Berry–eating rather than seed–eating birds account for the distribution of many understory species, and animal migrations are vertical (sometimes daily) or trans–equatorial rather than to rain patches (horizontal). A few plant species (lucerne, grains) are shared, but most differ from the hot desert areas.

Growing seasons are measured in days (40–70 days of growth is common) rather than months, and frosts may occur over most of the year; thus cold hardiness is as important, or more important, than drought hardiness.

There are few succulents at high altitudes; the cold freezes thick–leaved plants and ruptures the cells, although a very few "woolly" cacti can survive the cold as the thick hairs trap insulating air.

11.15

DESIGNERS' CHECKLIST

BROAD STRATEGIES

• Commence operations for freshwater infiltration at the top of catchments, and work downstream as plants establish.

• Give upwind areas the first attention for soil pitting and windbreak trees.

• Establish plant nucleii or oases at favoured sites and follow out on corridor planting.

• Spread pelleted seed over larger areas to await a favourable season.

GARDEN AND FOOD SUPPLY

• Establish shaded and mulched gardens within settlement.

• Establish settlement windbreak and shade trees.

• Extend successful species along corridors of sandy river beds, wadis, water runnels, foothills. Seek out favoured niches in rocks, seepages, shaded areas for high-value trees and vines.

• Establish water-harvesting swales and fields for wet-season storable crop. Swales may support trees and vines after a few rains have infiltrated into the soil.

WATER SUPPLY

• Primary drinking water can be supplied by tanks off roof areas.

• Gardens and firewood plantations are established using a combination of swales and drip irrigation.

• Broadscale crop needs both windbreak and water harvest at a ratio of 20 ha of run-off to 1 ha sown.

• Seek out safe dam sites near settlement, in shaded valleys or off streams diverted to drop silt.

• Store water in sand-filled dams or gabion-stabilised terraces.

• Use water wisely and route greywater to toilet use.

• Never use deep bores or pumped well water beyond the ability of the recharge areas to re-supply usage. Test all such water rigorously for salts, radioactives, nitrates, fluorine, and biological contamination.

• Wherever water is infiltrated into the ground, plant trees to keep salt levels down.

HEALTH

• Reduce dust in settlements via trees and soil pitting to avoid sinus and other problems.

• Check for water-born disease where children swim.

• Supply ample vitamins via home garden vegetables and fruits.

• Check plants, soils, and blood levels for essential minreals, especially zinc and iron.

• Reduce use of imported carbohydrates (sugars, starches) and rely instead on locally-grown crops.

11.16

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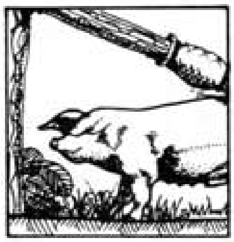

Chapter 12

HUMID COOL TO COLD CLIMATES

12.1 INTRODUCTION

This chapter deals with the cool to cold humid climates, where precipitation exceeds evaporation over the year. These climates differ from drylands in respect to evaporative effect, and from tropics in that frosts can regularly occur in winter. It is in this section also that we will deal with aspects unique to a cold climate (snow, ice, frozen ground, snow avalanche), and the character of settlements, landscapes, and husbandry in these regions.

Cool humid climates include Mediterranean areas, polewards to the boreal forests (the Taiga) that rim the tundra or cold deserts. For the most part, they are winter-wet climates, and suffer fogs and frosts. It is in the European and southwest Asian areas of cool humid climate that what we call contemporary or broadscale crop agriculture developed. This form of agriculture (high capital input, mechanised, energy-intensive, using artificial fertilisers and pesticides) has been inappropriately exported as an ideal to tropics and deserts, where neither soil, water, nor financial resources can support it.

In more sensible times, the cool (mesothermal) climates were a mosaic of mixed forests, extensive hedgerow, small fields, permanent meadows or prairie, and relatively small vegetable plots. Trade and export pressures from a subsidised agriculture have destroyed this stable use of land, and forced large-scale grain crop and feed-lot systems on farmers. Fields have been coalesced, hedgerow destroyed, and few significant forests remain within the farmed areas. Even where forests are preserved, the heavy industrial base of temperate areas, plus overuse of fossil fuels generally, have created widespread problems with acid rain, affecting the foothill forests and the thin soils of older shield areas, with secondary effects on water quality due to a release of excess metals from rocks and soils to streams.

Ozone production and soil losses (people now speak of the "desertification" of such areas as southern England, where wind effects on exposed broadscale soils sown to grains are pronounced) are slowly decreasing production on once-fertile fields. There is widespread pollution from the overuse of nitrogen fertilisers and biocides, compounded by such accidents as Chernobyl and persistent radioactives in acid soils, uplands, and field crops. Groundwater quality is decreased, and potable water supply becoming a problem.

The 40-year thrust for more and more production from temperate farms succeeded in producing surpluses in almost every farm product (grains, meats, dairy, and wines) at enormous cost to the public and the land. Thus, the central problem of the mesothermal climates and their societies is not (as in deserts and tropics) one of subsistence, but the very opposite. It is how to change energy and land use to create a sustainable future for such societies, without the huge public subsidy of modern agriculture.

However, since 1970 or thereabouts, there has been a widespread home garden movement, and an increasing development of urban farms under community control. The production (in dollar terms) of such home gardens now equals or exceeds farm production, and gardening is still increasing in popularity. Public attitudes to industrialised or polluted farm product is also changing due to data almost every day on the health effects from residual sprays, hormones, and excessive nitrogen or mineral content. Radioactive fallout has not helped to inspire consumer confidence in farm product, which promise to create a new category of human morbidity, called agricologenic disease (illnesses caused by farm chemicals).

As a result of better health education, animal fats, carbohydrates, and red meats are falling into disfavour as the effects of diet on diabetes, heart disease, obesity, and immune response are being elucidated. These effects are worsened by the more sedentary lifestyle of a mechanised society. There is a pronounced consumer swing to lighter diets, less fats, starches, and sugars, and a greater consumption of naturally produced vegetables, fruits, lean meats, fish, and poultry.

As many people now view modern agriculture, it has few essential roles to play in a sane future economy. Perhaps the production of lean protein and energy crops (firewood and liquid fuels, biogas and forest product) is the only foreseeable farm future. Conservation forestry for watershed protection and wildlife will certainly be a large part of future land use in the more affluent, leisured societies. As for food production, there is already ample evidence that the existing waste space within urban/suburban areas can produce most of the essential food of such areas.

The societies occupying mesothernal climates have achieved, for the most part, zero or negative population growth, and thus the pressure on land to produce has lessened while the land itself has been forced into uneconomic overproduction. Perhaps the best indicator of this stability in population is that more people are regarding farms and forests as recreational reserves, and near cities from 60–80% of farm income can be derived from *social* facilities, not farm product.

12.2 CHARACTERISTICS OF HUMID COOL CLIMATES

The cool humid climates are production areas for a great variety of berry crops: gooseberry; red, black, and white currants; blueberry; cranberry; cherry, salal, and service berry; and a variety of bramble berries. The woods contain many species of wild-gathered edible fungi, some of them long since cultivated on logs of oak, poplar, birch, and sassafras (shiitake, *Pleurotus*).

Evergreen and part-deciduous forests, fir forests (northern hemisphere), and species-rich meadows are found in the few areas still uncultivated, as are oaks and maples (for sugar), beeches and alder. In terms of "mast" production (the fallen food of acorns, beechnuts), truffles, and fungi, many natural forests are rich food resources. It is to be expected that the recently glaciated areas of these climatic regions will also be well-provided with lakes.

The waters of these lands can be rich in salmonid fish, suckers, carp, pike, and sturgeon. Pastures and remnant prairie and meadow are uniquely suited to these regions, and because of the often cool or cold and snowy winters, there is much emphasis on solid barns and houses, hay storage, field shelter, and root crop production for winter fodders and storage. Houses must be carefully constructed for winter warmth, and in the colder areas are often built with cellars or pit storages.

In these cold temperate areas of earth, outlined in Holdridge Life Zones (**Figure 5.2**), we are dealing with seasonal factors of frost, snow, ice, and (to the polar extremes), frozen ground. We also lose a great deal of heat energy, hence growth in plants and animals, to cold winds. Even on snow-free coasts, nearby mountains, plateaus, and inland snowfields advect cold air to the fields and forests.

Climatic subsets include the foggy coastal climates of northern California to Vancouver, western Euope, southern Chile and Tasmania, and the winterwet climates of the mid-latitudes. Most of Europe, China, Japan, North America to the northwest and northeast, Canada, and the Andean slopes and southern half of South America, the southeast and a section of southwest Australia, and mountain climates of southwest Asia can all be typified as cool humid areas, as are the outer slopes of the Himalayas and other high foothill areas in more tropical areas. The cool highlands of the tropics lack frosts, and some growth occurs all year.

Original vegetation was, or can be, mixed broadleaf and pine forests (evergreen or deciduous), wet sclerophyll forest, meadows, cool swamps and marshes, fens, and bogs. Periglacial lakes and moraine may occur over vast areas of the northern continents, and cool prairies or steppes develop in treeless areas recently covered by ice.

In general, the areas considered here have their coldest month below 0°C, and warmest above 10°C (mean or average temperatures). There is usually a winter-wet period, although rain can occur in any month, and drought occurs midlate summer. Most plant growth is in spring and summer, with a less marked period of autumn growth before the resting period of winter.

In Mediterranean areas, valley floors are favoured agricultural sites, and on the slopes, deeprooted and drought-resistant trees and vines are often grown Towards the older coniferous forests, soils are generally less fertile, but a band of brown/black clayloams of high fertility lies within the area of broadleaf forests; the centres of contemporary agriculture.

The mesothermal climates lie in the westerly wind belt, with the "roaring forties" (Latitude 40–45°) subarctic air in from polar lowpressure cells. In general, there is a 7–10 day sequence of frontal rains, with occasional easterly gales produced by large stable high-pressure cells to the east. Winds are particularly damaging when they blow off coastal seas in summer, as salt-burn affects trees and gardens.

Thus, except in cooler inland and sheltered sites, windbreak is essential for animal health and crop protection, and *permanent* forest edges must be developed both to retard fire and to prevent blowdown of single-age stands. Oak, willow, blackwood (*Acacia melanoxylon*), *Coprosma repens*, poplar, hawthorn, alder, aspen, and birch are just some of the ideal forest-edge trees for plantation protection.

On coasts, firs, cypress, *Araucaria* spp., *Coprosma*, waxberry (*Myrica*), and *Lycium* in snowfree areas provide frontline protection, with lower hedges of wormwood, rosemary, *Rosa multiflora*, hawthorn, and gorse (*Ulex*) around fields and gardens. Some of the taller grasses (pampas grass) or "fedges" of succulents and hardy vines greatly assist garden protection. Wind is a major determinant of yield over all coastal and upland regions of these climates.

In acidic peaty areas and turfs, fences of living peat or turf species can protect gardens. On cold exposed plateaus or coasts, drystone walls, soil banks, or ditch-and-bank are primary protection (many of these can later be planted to hardy shrubs or bamboo).

Low, flat valley sites, and especially those valleys at the foot of escarpments capped by high plateaus, may be subject to severe winter frosts. In mountain foothills, frost can lie all day in winter on the shaded side of valley slopes. Frosts affect pasture and herb-aceous plants by stopping growth or causing frost death by plant cell rupture. A great many species of plants from bracken fern to tomatoes are frost-killed, and many cool area farmers choose crop plants on the basis of frost-free days in the growing season, or (where frosts can occur in any month) by excluding from field culture any plant which is frost-susceptible over its growing season. Marginal or semi-hardy plants such as bamboo may survive frost if given an autumn dressing of fertiliser salts; high salt values in plant cells prevent cell rupture.

Cold humid air is viscous in flow, and stabilises in valleys as a dense are mass with a near-level upper surface. As most frosts form in calm clear weather, the upper cold air surface is rarely subject to strong winds, and this creates a marked frostline on hill slopes, often revealed by the contours joining frost-susceptible pines, jumipers, or evergreen trees.

Downslope cold air flow may have a distinct pulsing behaviour of about one minute where air flows from highlands, and this pulsing can create a series of surface waves in the cold air masses. Such waves are typical of large areas of the air above frosted ground.

Special frost-free sites, usually high on sun-facing valley slopes, in clearings on ridge forests, or in smaller clearings (less than 30 m across) in tall forest are therefore chosen growing sites in frosty areas.

12.3
SOILS

The striking characteristic of cool temperate soils is their ability to accumulate humus under natural regimes of forest and prairie or meadow. In this respect they differ from both tropical and arid-area soils, pH values in areas of poor drainage can be 3.5–4.5 (humic acids), and only over limestone, dolomite, and chalk deposits do soil pH values normally exceed 7. Traditionally, most soils have been limed to modify this acidity factor.

Another unique feature over vast areas of the northern hemisphere, and to a lesser extent in the southern hemisphere, are sheets of periglacial outwash, compacted till, moraine, and glacio-fluvial (ice and water) outwash, with downwind deposits of rock flour and fine particles (known as loess). Such areas are normally mineral-rich and fertile due to the mix of rock types in glacial debris. Braided wide streams and complex benches of glacial sediment along valleys typify the rivers with glacial headwaters, and low meltwater temperatures (46°C or so) may be maintained for most of the year. Acid waters containing humic acids, tannins, and saponins may issue from bogs and marshes. Even at pH 3.5, such streams (if unpolluted) can sustain good fish populations, although few molluscs occur due to low calcium availability.

It was in these regions that plough agriculture developed, with the old traditions of "high farming", which included the concepts of crop rotation (over 49 years) and a rest period, ley of green crop, or pasture. Because livestock had to be shedded in the colder areas, manure spreading on fields and hay feed stores in barns were also developed, hence ley crop, silage, permanent pasture management, intensive livestock husbandry, and root crop for winter storage (turnip, beet, potato, carrot, parsnip). Traditional grains were barley, oats, wheat, and rye, and traditional foods were meats, vegetables, and breads. Many methods of winter storage of foods were developed, ranging from burial of butters and acorns in bogs to ice storages, pits, cellars, and silage systems for fodder.

Soil, for the most part (excepting some sandy coasts) have good structure and clay fractions, high natural humus, and good CEC capacity. Adjusted for pH, micronutrients, and trace elements they are ideal crop soils, unless derived from acidic rocks (granite, quartzite, gneiss), where peats are developed.

12.4
LANDFORM AND WATER CONSERVATION

Open water storages are peculiarly appropriate to the mesothermal landscape. Soils generally possess sufficient clay fractions (over 40%) to ensure secure dam walls, evaporation does not exceeds precipitation in normal years, and there is a wide range of plant and animal species dependent on water for their production.

It is in the classic "S" profile of the humid landscape that Yeomans[6] developed his Keyline approach to farm water management, which integrates open water storage with soil reconditioning, soil water storage, fencing, and farm forestry in a whole system design. The classic Keyline system of gravity flow irrigation refers only to gentle foothill country in the headwater regions of first and second order streams, but skilled design over a very wide range of soils and of landscapes can achieve the essentials of drought-proofing by gravity-flow irrigation, soil conditioning prior to forest or pasture establishment, fire control by downslope flooding, and integrated forest farm systems.

It is in humid landscapes that the techniques of water storage, diversion, and the various uses of stream or overland water flow can be most developed.

The overriding design input into humid-area landscape is therefore planned on the basis of water management, followed by access planning (roads and tracks), then plant and animal system planning. In water planning, we start from the highest accessible slopes, and work out methods to lead water flow via the longest routes downhill (working on or near contour), creating small dams, swales, rip-lines, and (where appropriate) and energy systems to take advantage of the abundant rainfall.

Water has all of the following tasks or duties in the landscape:

- As soil and pond storage, to irrigate crops and forests.
- In homes, for cooking, drinking, cleaning, and toilet uses.
- As a source of energy via turbines or as hydraulic pressure.
- In growing fish and aquatic plants; as a growing medium in itself.
- As a carrier for nutrients. Nutrients added to upstream or uphill areas are distributed downstream to crops.
- Recreational and aesthetic uses.

12.5
SETTLEMENT AND HOUSE DESIGN

The greatest cost in house maintenance in temperate cold areas is that of space and water heating; together, these may make up 80% of all domestic energy costs. Both settlement design overall and house design in detail is a critical conservation factor in human occupation of wintercold areas, more so than in tropical areas, or in hot deserts.

Not only housing, but barns, outbuildings, and livestock shelters must be solid, well-designed, and carefully assessed for thermal efficiency.

SETTLEMENT DESIGN

Settlement site choice, and the surrounding plantings in landscape, are probably so critical as to provide for 70% of the conservation of heat energy in cool climates; actual structural techniques cope with the rest. Thus, in creating a sustainable settlement, the following factors are important.

- Village or streets aligned eastwest at the mid-slope (thermal belt) of a sunfacing slope, preferably with forests and high water storages above the site.
- Housing closely placed or conjoined at east and west walls, and preferably of two to four stories. These factors reduce insulation costs and create a compact site.
- Careful planning of accessory landscaping to pro-

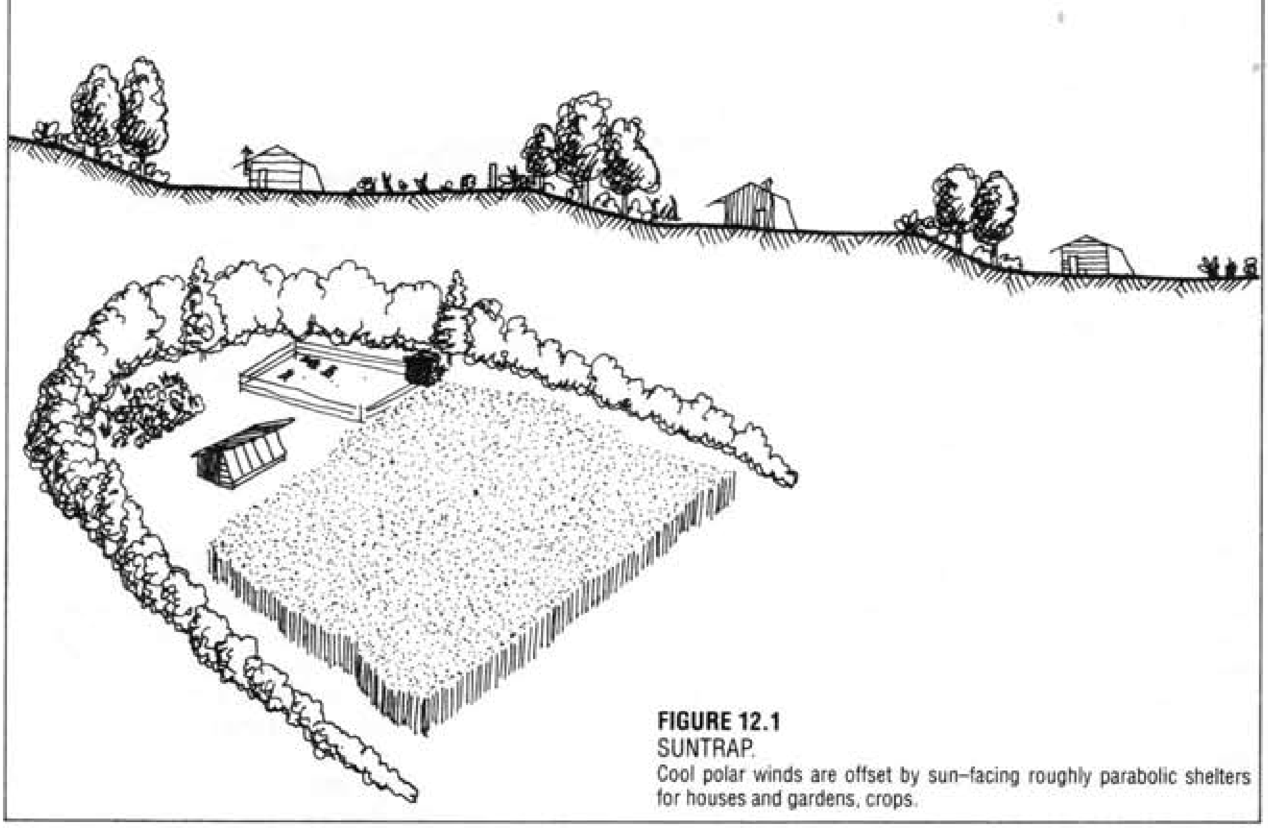

FIGURE 12.1
SUNTRAP.
Cool polar winds are offset by sun-facing roughly parabolic shelters for houses and gardens, crops.