Chapter 10

THE HUMID TROPICS

10.1

INTRODUCTION

The subsets of climatic zones included in this chapter specifically exclude arid tropics, which are included in Chapter 11, together with cold arid areas. As plants and techniques do not split off neatly into climatic areas, the following three chapters should be read in total for any one site. A subtropical site, for instance, can have quite severe frosts, cold winds, torrential summer rains, and 7–9 months of drought, so that it needs the strategies, earthworks, and species suited to temperate, arid, and tropical humid climatic regimes. However, it is true that soils and climatic characteristics do dictate the specific broad design responses.

Some special topics of the humid tropics are those of soils, mulch sources, planning for polycultures, and appropriate house construction, each of which is given a section.

In the wet tropics, heat and high rainfall would leach most mobile nutrients from soils, except for the biomass of the great variety of plants, which contain 80–90% of the available nutrients. Humus is an essential soil fraction, and humus creation must be given considerable emphasis as prerequisite to sustainability.

Inappropriate strategies are those of bare–soil cultivation, or intensive clearing and burning in short cycles (less than 8 years or so) for cropping. Appropriate strategies involve complex and multi–storied plant systems designed to yield basic staples, create mulch, and preserve soil nutrients.

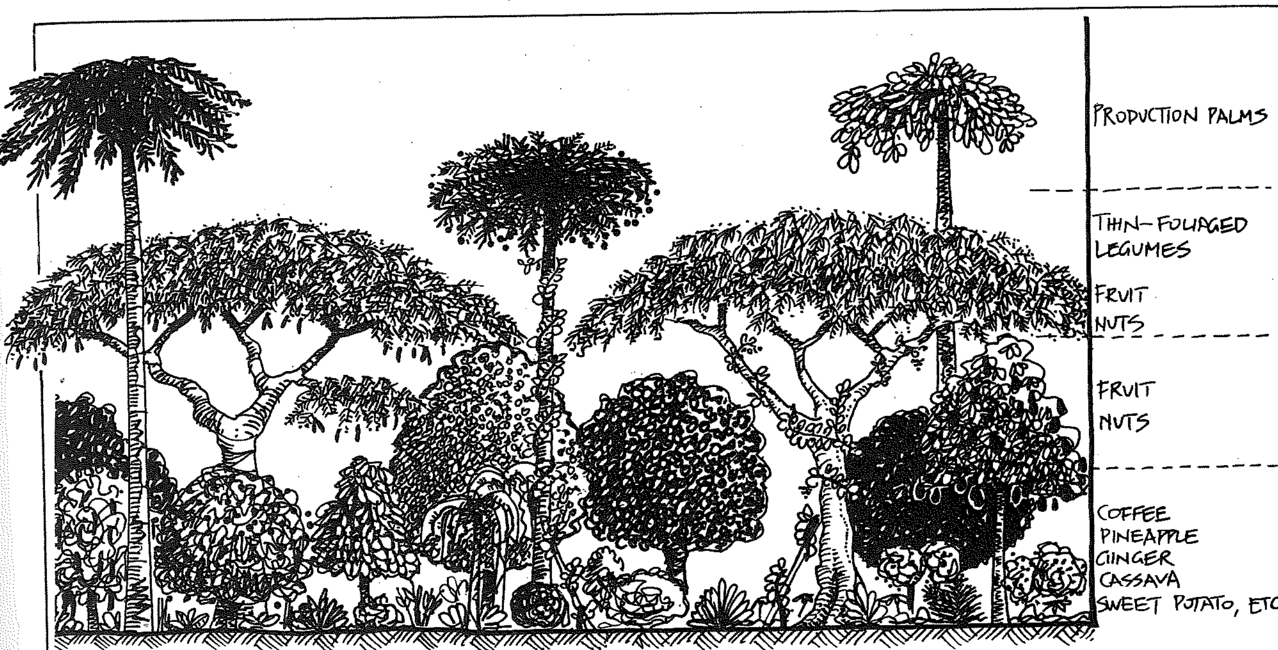
James Fox in *Harvest of the Palm* (1977), has been one of the few who have analysed the social changes and loss of self–reliance following the abandonment of ancient and balanced palm polycultures in Indonesia. Ancient tropical civilisations have been noted for their stability, indicating that sustainable land use patterns are an essential prerequisite for social harmony.

The Food and Agriculture Organization of the United Nations (FAO) admits to failure in transferring mechanised monocultural sustems (barely sustainable in temperate moist areas) to fragile African or tropical soils. It is a wonder that this was tried at all in modern times; the clearing and cultivation of tropical soils has for decades proved disastrous, and most ecologists would have predicted this failure by the early 1950's.

Complex perennial fodder and food systems are known to be stable, but are not as yet part of the officially funded agricultures from such sources as the World Bank. Deserts present even more fragile systems and need greater skills to stabilise and manage. The most inappropriate advisor is an agriculturalist trained in "modern" techniques. What is needed is continuous, local education of experienced people and a lateral transfer of their evolved skills. Emphasis in such education should range from an analysis of health and environmental problems to practical solutions, with sophisticated plant/animal/technological assemblies adapted to local food preferences, nutritional needs, and cultural requirements.

Romantic literature on the "easy" tropical life leaves out the skin cancers, rodent ulcers, dengue fever, filaria, malaria, chronic bowel and skin disease, and the constant battle with rampant growth that is an everyday experience at Latitudes 0–25°. That, and the pythons, ticks, termites, rain, mould, and lethargy caused by heat exhaustion. With the increasing loss of atmospheric ozone, it is folly for fair or red–haired Europeans to expose bare skin to the tropical sun—a cause of skin cancer in Australia and "*haole* rot" (a form of fungal bleaching of the skin) in Hawaii.

Humid heat induces a lethargy compounded by chronic illness in many populations. Water–borne and mosquito–transmitted diseases are almost impossible to totally control, given the aerial resevoirs of water developed by palms and bromeliads. In houses, induced cross–ventilation and careful construction for mosquito control are essentials, as are plant systems



based on a tree–species polyculture; the two combine very well to reduce climatic extremes.

We can largely emulate the tropical forests themselves in our garden systems, establishing a dominant series of legumes, palms and useful trees with a complex understory and ground layer of useful herbaceous and leguminous food and fodder plants; vines and epiphytes can complex this situation as it evolves. In the wet–dry tropics, more open palm polycultures are appropriate; the excesses of heat, light and rain are best modified by an open canopy of palm fronds and the fern–like leaves of tree legumes.

10.2
CLIMATIC TYPES
(Based on Trewartha, 1954)

WET TROPICS

These are the river basins and wet coasts from Latitudes 0–25°. Major localities are the Amazon and Congo basins, Central America, Sri Lanka, Malaya, Borneo coasts, and New Guinea. This climate covers about 10% of the earth's surface (5% of the human population). It is heavily occupied only where terraced alkaline volcanic soils enable sustained cultivation (Java). It contains remnant tribes of hunter–gatherers (often pygmoid) in remaining forests, and is rapidly being ruined by over–exploitation of forests, mining and extensive cattle rearing, mostly developed by large corporations. Hence, there is a recent tendency for catastrophic wildfires to develop in logged areas such as Borneo, and for soils to be leached to low fertility, or eroded to ferricrete or silcrete subsoils.

The sun is mostly overhead, with temperature fluctuating little at about 21–32°C (70–90°F). Humidity is

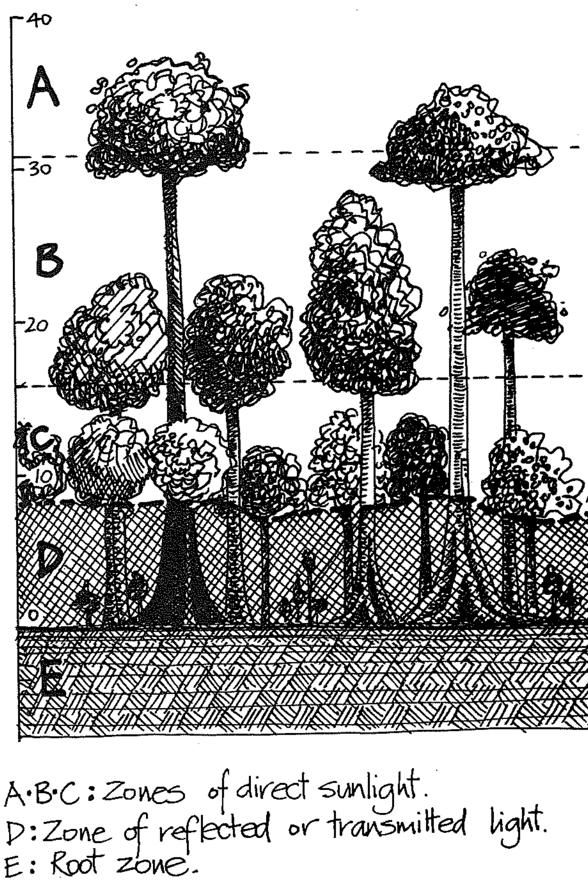


FIGURE 10.1
STRUCTURE OF A WET TROPICAL FOREST
Dense planting is possible, and beneficial near villages; species assemblies are simplified on the broadscale. Levels in natural forests are also indicated (after Moore, *New Scientist*, 21/8/86).

constantly high, frost unknown. Rainfall is from 152–328 cm (60–129 inches), with rain most days and frequent thunderstorms (75 to 150/year), usually towards evening or late afternoon.

The landscape features perennial streams, deeply weathered and rotten rock over bedrock (regolith), and rounded hills. There is rapid water run–off and evaporation, with swamps confined to coasts and lowlands. Rivers usually have flood–plains and extensive alluvial plains and deltaic deposits. Access inland is often by rivers and tributaries.

The vegetation is luxurious, best developed as broadleaf rainforest with lianas and epiphytes, very much mixed as to species—up to 800 tree species per square kilometre. The shaded floor of the forest contains little growth and has subdued light. Mangroves are extensive on appropriate coastal and estuarine sites. Growth is rapid, uninterrupted and continuous. Insects and birds are plentiful and varied. Most fauna is nocturnal and arboreal, and there are abundant fish and aquatic species. Ground grazers are rare and large herd species do not occur.

About 85% of nutrients are held in plants or animals, so the soils themselves are infertile especially if clear–cultivated, tending to erode and leach to insoluble oxides of iron and aluminium. Only terraces, flood–plains and new volcanos keep some soil fertility replenished or held if land is cultivated.

Staple cultivated foods are plantain and banana, cassava, yams, coconut, corn, taro, paddy rice, ducks, pigs, poultry, and fish. Trade and plantation crops are spices, copra, palm oil, cacao, rubber, banana, manilla hemp, rare hardwoods, balsa, tropical nuts, chicle, and drug plants.

Housing is usually raised, steep roofed, thatched, with permeable walls, and screened. Health problems relate to sewage disposal, insect vectors, and skin fungi.

Design essentials are for:

- Hygenic faeces disposal.
- Clean water sources.
- Integrated and benign insect control techniques.
- Gradual replacement of ground crops by trees.
- Preservation of natural stands of trees.
- Development of river versus road traffic.
- Evolution of natural products .
- No–dig (mulch) techniques on root crops.
- Domestic foragers for snail and insect pests.
- Appropriate medicinal plants.

WET–DRY TROPICS

These adjoin the wet tropics but are poleward of them. They take up about 15% of earth's surface from Latitudes 0°–25°, unbalanced in favour of the southern hemisphere. The Campos, Llanos, Gran Chaco areas of South America, parts of Central America, encircling the Congo basin, and many central Pacific islands (Hawaii) are all wet–dry tropical areas, most now developed to grazing.

Winter, the low–sun period, is the dry time, when clear skies and intense sunlight take day temperatures to 38°C (100°F) or more. Humidity is low, and strong dessicating winds may blow. Summer, the high–sun period, is like the wet tropics, but episodic flooding is more common and natural erosion therefore greater. There are no frosts, and temperatures range 21–27°C (70–80°F) in the wet season, 32–38°C (90–100°F) in dry season. Rainfall is 25–152 cm (10–60 inches), decreasing towards desert margins. Windward inland slopes and coastal mountains may receive excessive rain to 1016 cm (400 inches), but rain is erratic and least predictable towards the desert margins. Rain shadows evolve on leeslopes or in the lee of mountains.

The landscape is of intermittent streams, some wadis and flood plains, karst (limestone) areas with sinkholes, cenotes, and absence of surface water (Yucatan, Mexico). Hills are rounded, but gully erosion can develop rapidly on slopes. Extensive inland swamps may develop in flooded areas, and lakes in rifts are common (Africa). Rivers often have dangerous barways of silt and sand due to active erosion sequences.

These regions contain the vast savannah grasslands of the tropics, with thorn–bush and flat–topped *Acacia* trees (Africa), evolving to steppe grassland on plateaus, with baobabs and dry–deciduous trees. Grasses reach 1–6 m (4–20 feet) in the wet season, and are often burnt off. African areas contain enormous numbers of herd species: zebra, gnu, antelope, and therefore large carnivores. Arboreal species occur only within tree islands and the gallery forests of valleys. There are termites, ostrich, rhea, locust, and large numbers of reptile species and insects.

Soils are generally more fertile and alkaline than the wet tropics, especially where they are less leached by rain towards the deserts. Cultivated land is still at risk from erratic rain and erosion, leaching, and wind effects. Due to overgrazing and fire, erosion may extend the desert into these areas, or into dry–summer subtropics. Serious soil erosion results from short–term shifting cultivation (less than 15 years fallow period).

Staples are corn, millet, wheat, beans, potatoes, cucurbits, peanuts, cattle and goats, sheep, and game products. Herding of low–yield large herds is a major erosion hazard. Plantation crops are sugar, cotton, peanuts, pineapple, sisal. Exports are cattle and sheep products, and hardwoods from gallery forests.

Houses and granaries are generally mud or pise with thatch.

Design essentials are for:

- Small domestic water storage and reticulation.
- Hedgerow against winds.
- In–crop tree legumes such as *Acacia albida*.
- Improved stock varieties and stock management.
- Natural herding system of local herd species.
- Mulch use of grasses.
- Increased tree crop of high forage value.
- Decreased fire frequency.
- Tree stands for fuel and structural timber.
- No–tillage (cut and mulch) grain techniques.
- Low bunds for water retention.

• Chisel plow and sod–seeding techniques.

• Greater reliance on in–village tree crop near wells and ponds.

• Reclamation of eroded lands using pioneer species.

• Keyline techniques of flood control.

• Soakage pits and impoundment of run–off by low bunds or swales across slopes.

• Tree forage and tall grass hand–fed to domestic stock .

• The use of manures in gardens.

• The development of domestic fuelwood systems near villages.

MONSOON TROPICS

These are really a sub–type of wet–dry tropics, but influenced by nearby continental land masses and oceanic winds onshore. They are confined to the Indo–Thailand region, northern Australia, East Java, Timor, southern New Guinea, and extend Latitude 0° to 35° north in India. Despite only about 8–10% of the world's land surface, monsoon areas contain large human populations.

Late summer heating of the continents causes onshore sea winds and (with luck) heavy rains. The dry (winter) season reverses winds from cool interiors to coasts, giving a cool period not experienced in the wet–dry tropics (temperatures: 13–21°C—55°–70°F). Temperatures rise, and dry hot winds develop (to over 38°C—100°F) in spring, with heat increasing until the onset of the monsoon . About 60% of the rain falls in summer, but rain is erratic and varies from 102–1016 cm (40–400 inches), depending on topography and distance from the coast. Floods and droughts are equally unpredictable, but common. Most activities are determined by the monsoon rain (transport, fishing, farming).

Tropical forests once clothed the hill slopes and river plains, and grasslands extended towards deserts as savannah. Population pressure, deforestation, and marginal agriculture has devastated this ecology in India. Dry–deciduous broadleaves are common, teak and bamboo once extensive. Tree canopy is less dense than in wet tropics, so that dense understory is also developed. Mangroves occupy river mouths and low coasts. Large native animals are now rare in the Indian sub–continent, but reptile life is abundant, as are feral or native deer, buffalo, and primates. Monsoon Ausralia is better vegetated, with scattered eucalypt and *Acacia* trees, riverine forests, and very low human populations to date. Large marsupials, feral buffalo, and marsh waterfowl are abundant.

Soils are lateritic, often very hard in the dry season, and of low nutrient status. Some are cracking clays. Housing is often mud–pole structures, thatched, steep–roofed, with wide eaves and good drainage for wet period.

Design essentials are similar to those of the wet–dry tropics.

10.3

TROPICAL SOILS

Special problems arise with tropical soils, in that except in areas of recent vulcanism such as Indonesia, soils are old (not renewed by glaciation) and deeply leached. Most of the silica and calcium is in low supply. In clays, aluminium ions substitute for some silica ions, giving soil particles a net negative charge. Especially in the oxidic kaolinitic soils (common in weathered volcanics) only kaolin clays and oxides of iron–aluminium remain. In these soils, the charge or cation exchange capacity (CEC) of the soils is *affected by pH*. Once cleared, the humic particles leach out to about 30% of prior levels, and infertility appears in such crops as banana and sugar cane. There are a few ways to restore the soil's ability to hold nutrients (Wayne Ralph, "Managing Some Tropical Soils" in *Rural Research* No. 117, pp. 15–16):

• Restore humus with green crop, and especially perennials such as *Leucaena* and tree legumes generally Any cultivation loses humus as carbon dioxide, so try to grow plants with intercrop.

• Now, add *small* quantities of superphosphate at frequent intervals so that plants can take it up before leaching. If possible, add fine crushed basalt, a scatter of cement powder, and use shredded bamboo or cane mulches for silica and calcium. Increase pH with lime after trees and green crop are growing well.

• Whatever is added or available as fertiliser, give as a light spread *all year at 6–week intervals*, until plants are well grown. If at all possible, substitute perennial for annual crop, and *never* practice frequent cultivation.

Basalt, cement powder, coral, and bamboo mulch supply essential nutrients and increase soil pH, hence increase the negative charge on soil particles and their ability to hold calcium, sodium, phosphates against leaching.

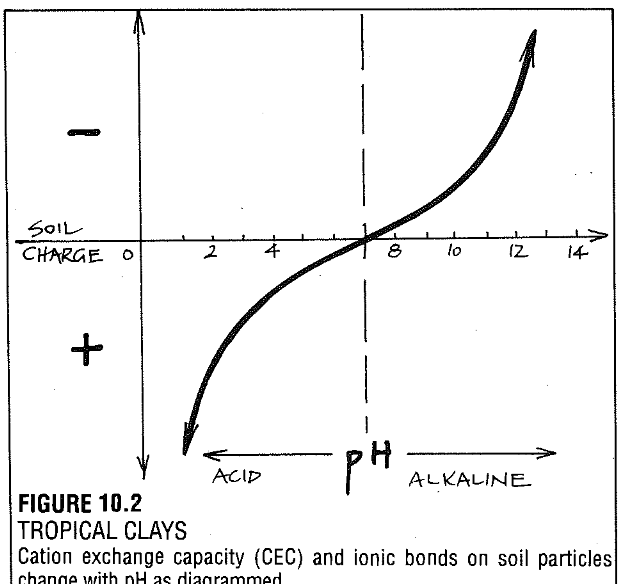


FIGURE 10.2
TROPICAL CLAYS
Cation exchange capacity (CEC) and ionic bonds on soil particles change with pH as diagrammed.

On coral cays, the calcium–rich sands bind to phosphate to form insoluble calcium tri–phosphate, so that a sort of cement (*platin* or calcrete) forms. This may be naturally evolved from the guano of seabirds, but superphosphate rapidly forms the *platin* by its greater solubility. In calcium rich tropical soils, fine rock phosphate yields more slowly and is therefore more likely to provide long–term benefits. A return of crop wastes as mulch is also essential, which can *reduce* pH in coral sands (pH 8–9) to a level nearer to pH 6.5 or 7, which is suitable for gardens.

In fresh volcanic areas, or areas with volcanic dust deposits, soils are sufficiently rich to sustain intensive agriculture without such aids, but constant cropping will exhaust even these soils.

There are many excellent tropical soils such as the alkaline volcanic soils of Indonesia, which support rich terrace and palm polyculture systems, and many tropical high–island soils where dolomite tops, or forms a mosaic with, recent volcanics. Apart from testing for minor elements, the addition a of mulch–manure mix creates excellent gardens on such soils, and plants show only minor nitrogen deficiences. These deficiencies can be eliminated by legume intercrop and manures.

In the long term we must rely on tree and ground legumes to keep up soil health in the tropics. Destructive approaches (now very well demonstrated) combine forest clearing, bare–soil cropping, and careless water run–off management to make desolate baked clays, brick–like and hostile, out of once–rich tropical forests. We have (as yet) no categories of "crimes against nature", but these will prove, in the future, to be some of the worst.

DEEP GRANITIC SANDS

In soils over rotted granites, such as are found on the high islands of the Indian Ocean, the Deccan in India, and where granites are left as inselbergs (domed hills), a peculiar problem arises in that open, coarse, granitic sands, often very deep, will not retain mulch beyond one growing season. There are two approaches to these free–draining and low–nutrient soils:

Broadscale

Palms, *Albizzia* spp., *Inga* spp., *Acacia* spp., a general planting of adapted leguminous trees, and other native vegetation will establish a light canopy of leaves if small amounts of nutrient are added at regular intervals. Palms planted in mulch–filled pits will then establish a high crown cover, and the detritus from legumes can be used to establish more valuable fruit trees, always retaining a *complete root web* of legumes. Palm trunks are ideal trellis for vanilla and passionfruit crop. Niches and clefts in the granite mass itself will hold pockets of soil and mulch for valuable trees, and vines will establish there to cover the granite slabs, which maintain heat and ripen crop effectively.

It is the mycelial web of the pioneer legume roots which enables us to maintain the benefit of applied nutrients, to reduce water use, and to establish fruiting trees (mango, cashew, pomegranate, persimmon, citrus, tamarind, lychee, custard apple, avocado) in such sparse and drought–prone soils. Drainage is, of course, excellent, and deep–rooting trees thrive. Palms suited to these sites are date, coconut, doum, and *Borassus* palms.

Gardens

It is effective to excavate long trenches in the loose sand (1–2 m wide, 1–1.5 m deep), to lay in a sheet–plastic base (upturned at one end only) or to line the trench thickly with cardboard, paper, carpet, and leaf and then to backfill with sandy loam. The deep sealed layer holds water and leached mulch, and household waste water can be led into these trenches to provide root water and nutrients.

Otherwise, we can build log–boxes above ground level, carpet the box base with plastic or thick paper,

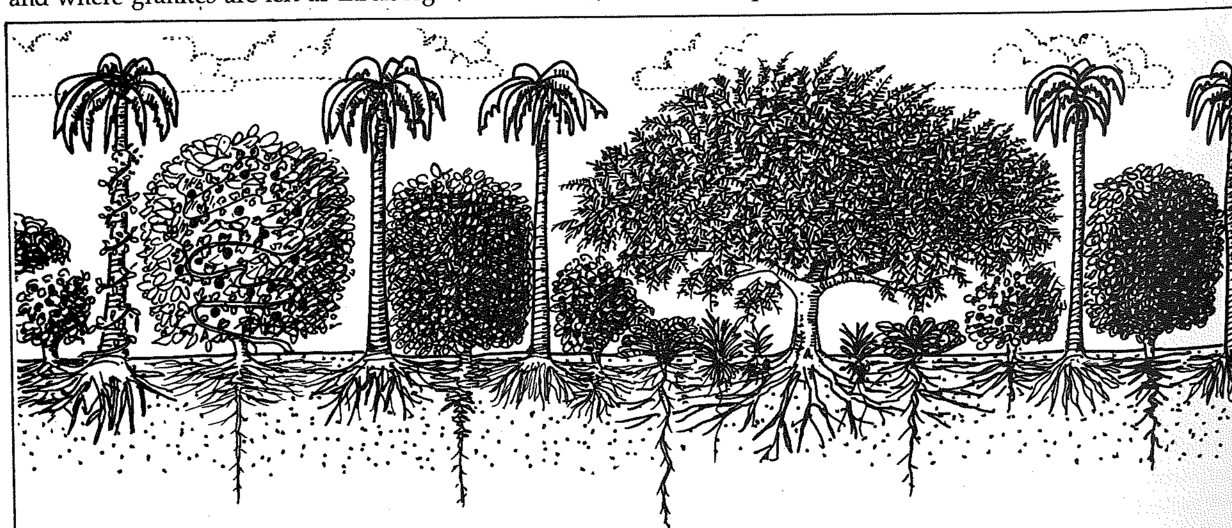


Figure 10.3
BROADSCALE TREE CROP IN LOOSE GRANITIC SANDS

and fill with humus–sand mixes for green crop and vegetables, top–mulching as needed. Large domestic water tanks, gleyed ponds, solid granite dams, and underground plastic–lined cisterns back–filled with sand will hold water.

SOIL LIFE IN THE TROPICS AND SUB–TROPICS

Termites, ants, and some worms are the obvious soil mesofauna of many arid and humid subtropical areas. Both ants and termites are very active in the transport of rotted rock and subsoil to the surface, in opening up galleries for the infiltration of water, and in the breakdown of woody and leafy plant material. Some species create large mounds, others build underground compost heaps for fungal culture, and all are active burrowers and builders.

Termites may have a decisive role in the dynamic and delicate balance between the erosion of surface soil and the replacement of the soil by subsoil and rotted rock particles. They certainly have an important role in plant succession and distribution in savannah areas, or where termite and ant mounds are the only well–drained or elevated sites in a landscape subject to floods, or where impermeable clays underlie thin peats (usually with acid anaerobic soils). In these situations the spoil heaps present an ideal site for pioneer vegetation or adapted crop planting.

Harris (1971) records that both the leaf–cutter ant in South America and termite mounds in Uganda assist forest spread or establish islands of taller vegetation in grasslands on their mounds or colonies. I have also observed this in the granite country in Hyderabad, India, and on acid peatlands in Tasmania. Such mounds protect soils from fire, waterlogging, and poor aeration. In humid areas, some such sequence as tall grasses (*Pennisetum*, *Eragrostis*) are followed by shrubs such as castor oil bean, *Prosopis*, and thorny legumes. Finally, an understory and forest may develop from larger trees such as tamarind, *Vitex*, *Sapium*, or palms dominant.

Thus, we can start this process or a modest version of it by seeding into termite or ant mounds using similar species; even low ant–heaps may present a site for ground cover pioneers in grasslands. Harris records crops such as sisal, cotton, and tobacco deliberately cultivated on large mounds in grasslands. Palms and coffee can have much of their outer bark removed by termites without suffering loss of production. Termites may greatly assist the primary breakdown of logs, coarse stems, and hard leaf material used as mulch in plantations of coffee, tea, or bananas.

It is a matter of specifying (by observation and local report) which useful crops or trees are left alone on mounds, which are attacked but remain productive, and which actually benefit by association with a local termite or ant species. Planting in ant or termite mounds is a particular example of niche gardening widely applicable to the tropics. I have successfully germinated daikon radish in ant heaps in grasslands as part of a changeover to crop production.

Ant and termite mounds present a rich deposit of calcium and potash, better aeration of soil, and a faster infiltration of water to release minerals from such rocks as granites, which noticeably rot or erode faster when buried in a free–infiltration soil environment.

SOURCES OF HUMUS FOR TROPICAL SOILS

As humus in the soil provides a good CEC, we must look to the provision of such humus as a priority. Some sources are:

- Logs and branches of trees. These are sometimes rotted in wet terraces or piled up as rough mulch around new tree plantings. Palm wastes are often plentiful.
- Detritus from stands of bamboo, pines, *Casuarinas*.
- Aquatic weed mats and emergent water weeds.
- Crop wastes and manures, household wastes.
- Hedgerow, forage, and specially–grown mulch plants.
- Green mulch and ground cover.

Logs and Branches (Rough Mulch)

The rapid breakdown of wood under the combined influence of rain, heat, termites and fungi means that we can lever whole logs together, or in line cross–slope to act as planting sites. This technique is most useful on bare clay soils, eroded areas, and isolated atolls (using the trunks of old palm trees).

In Hawaii, a traditional strategy is to rot the logs of

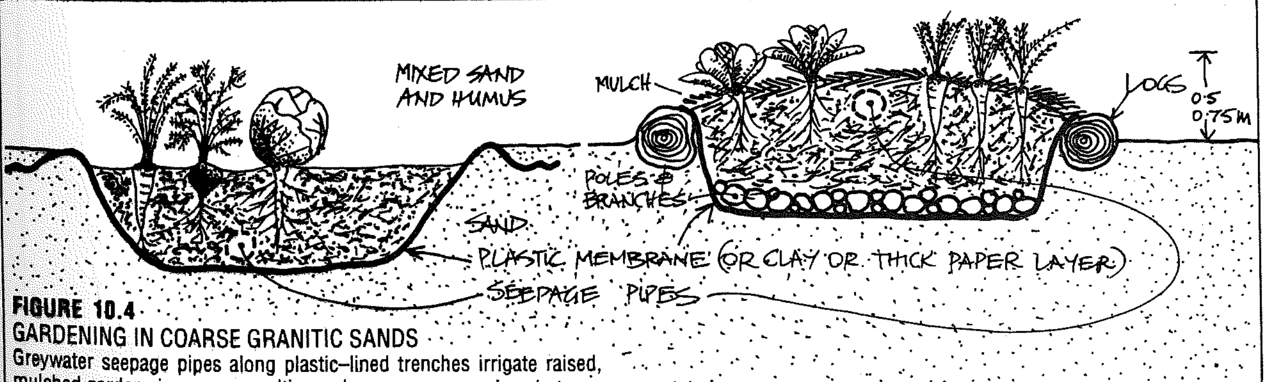


FIGURE 10.4
GARDENING IN COARSE GRANITIC SANDS
Greywater seepage pipes along plastic–lined trenches irrigate raised, mulched gardens in coarse granitic sands.

the kukui tree (*Aleurites moluccensis*) in the shallow water of taro terraces. As logs rot, an edible fungi appears which is taken off as crop. The remaining log is then crushed and spread in the taro terrace. Leaves and branches of kukui and other forest trees were gathered for the same purpose (terrace mulch).

Marjorie Spears, in Queensland, Australia, has successfully built temporary roughwood terraces across a deforested slope using rejected logs, and created a complex and rich garden based on this strategy and green legume mulch. Logs are available from palms, although fast–growing *acacia* species can be previously close–planted for this purpose (**Figure 10.5**).

Detritus

Several plant species (most palms, bamboo thickets, *Casuarina*, and many *Acacia* species) provide silica–rich mulch, as do grain and nut husks and residues from copra operations. This can be applied as shredded or chopped mulch to crop or to the base of newly–planted trees. The silica is released for growth, and has the secondary effect, in alkaline island soils, of reducing pH (from 8.5 to 6.5 in my trials on coral islands).

Of particular value are the fronds and spathes of palms, shredded or whole, and the stems and spathes of bamboo. Both have essential structural uses, and larger stands can be used to produce mulch.

Aquatic Weeds

Floating aquatics, including the water–fern *Azolla* (several species), the water–lettuce (*Pistia*), water hyacinth (*Eichornia*), and algal mats or fern fronds, plus reeds and rushes gathered from ditches, are excellent crop mulch. *Azolla* has largely replaced kukui (*Aleurites*) as a taro mulch in Hawaii. *Pistia* has been successfully used in Africa, and water hyacinth in many areas.

Azolla and algae such as *Anabaena* (one species of which "nests" in the glutinous sacs in *Azolla*) provide nitrogen. In the dry–wet tropics, shallow flood–water bunds collect or produce these plants, which can be gathered as rolls of dry material when the water dries out in the winter period, thus providing garden mulch in abundance from temporarily impounded water. John Selman of Cooktown (Australia) has used algal rolls in this way for his garden plants.

Crop Wastes and Manures

The husks of corn, kitchen wastes (including bones), and human and animal manures are invaluable tropical garden mulches and nutrients, and most need only burial near tree roots or in growing mounds for safe disposal. Cardboard and newspaper, where available, are valuable grass–suppressing weed mulches, and a cover of nut husks completes the job. In the Seychelles, cinnamon leaves and branches from pollarded stumps are considered an excellent mulch for vegetable crop; and the bark is a valuable spice.

Hedgerow and Mulch Plants

All hedgerow (*Hibiscus, Casuarina*, banna grass, palms, leguminous trees such as *Gliricidia, Acacia* and *Prosopis*) are almost continual mulch sources. The legumes provide in–crop shelter (see later section on avenue cropping). Lower garden windbreak, especially lemongrass (*Cymbopogon citratus*) and comfrey (*Symphytum officinale*) are as useful in preventing kikuyu grass intrusion as they are for repetitive cutting for mulch in the vegetable garden. Many people now use both these species as a combined kikuyu barrier and mulch crop (**Figure 10.6**).

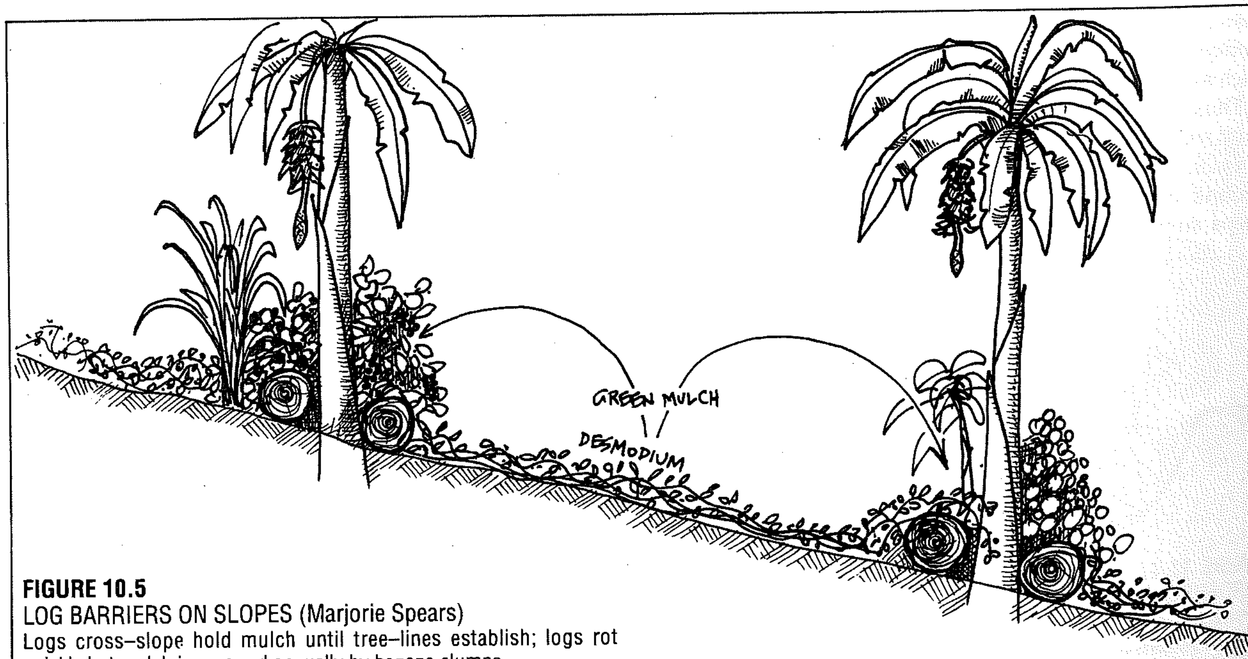


FIGURE 10.5
LOG BARRIERS ON SLOPES (Marjorie Spears)
Logs cross–slope hold mulch until tree–lines establish; logs rot quickly but mulch is renewed annually by banana clumps.

Green Manures and Ground Covers

In and around gardens and trees, soft herbaceous plants such as nasturtium, comfrey, marigolds, tobacco plants, and the tops of mature taro plants and other *Araceae* not only suppress grass, but provide a constant source of "slash" mulch. Even more valuable are such soft legumes as *Sesbania*, vetch, Haifa clover, cowpea, lablab bean, soya bean, *Desmodium*, *Suratro*, and *Centrosema*. These can be slashed or (in wet–dry tropics) interplanted with grains to give a nitrogenous ground cover, aiding in the suppression of grasses. Lablab dies down just before grains ripen in the winter dry season.

Thus, a combination of growing and gathering mulch enables us to create a rich humus for gardens over clays or sands, in loose volanic cinder, on *a 'a* lava, and in loose coral atoll sands. Each of these situations can successfully produce mulch.

Some difficult mulch such as *hibiscus*, *Lantana*, and weeds which tend to resprout from cuttings or seed if mulched (several grasses and hedge species) can be routed to gardens via poultry or cattle pens (where seeds are removed and foliage eaten). They can also be shredded for anaerobic digestion in biogas plants, bagged in large plastic bales exposed to the sun (where they "cook" to a weed–free silage), or simply bundled and immersed to rot in covered water pits. In fact, some such re–routing is ideal for the primary processing of plant wastes that promise to infest gardens if untreated. Pigs eliminate or eat the nut–grasses, rhizomes, bulbs, and sedges that resprout from compost.

All else failing, even a plastic sheet mulch has excellent effects on row crop, preventing rain splash and nutrient leaching, and at the same time condensing groundwater at night. It does not, however, add to the humus content of soils, nor to the cation capacity of soil structure, and may even release unwanted chemicals to the soil.

The value of surface mulch in weed suppression is a major factor in lowering garden work. For this reason, any mulch should be thickly applied 20–25 cm (8–20 inches) deep when first establishing home gardens. Later mulch can be derived from green herbage and borders or windbreaks.

TABLE 10.1
CROP YIELDS UNDER SELECTED MULCHES

MULCHES	Maize	Cowpea	Soyabean	Cassava
Rice husks	3.7	1.1	0.8	**28.3***
Pennesetum Straw	3.3	1.2	**1.4**	14.2
Elephant grass	3.3	0.9	1.3	16.6
Millet straw *(Panicum)*	3.6	**2.1**	**1.5**	15.5
Legume wastes	**4.3**	1.0	1.1	15.5
Sawdust	3.7	0.9	**1.9**	20.5
Bare ground	3.0	0.6	0.6	16.4

*Heavy yields are emphasized.
[After B. N. Okigboand R. Lal, *Residue mulches and agriculture.*]

B. N. Okigbo and R. Lal in *Residue Mulches and Agrisilviculture* (International Conference on Ecological Agriculture, Montreal, 1978), in mapping strategies to cope with increasing land pressures, found that no–tillage systems maintained or gained yields for maize in Nigeria, and increased yields from mulched crop for cowpea, soya bean and cassava.

I have selected out some natural mulches from the more extensive original table given. Mulch trials are compared with bare ground (on the last line of **Table 10.1**)

Maize had a marked positive response to legume straws or waterplant (*Pistia*) mulch, while the legumes themselves responded well to grass and sawdust mulch, and cassava to both legume and grain husk wastes.

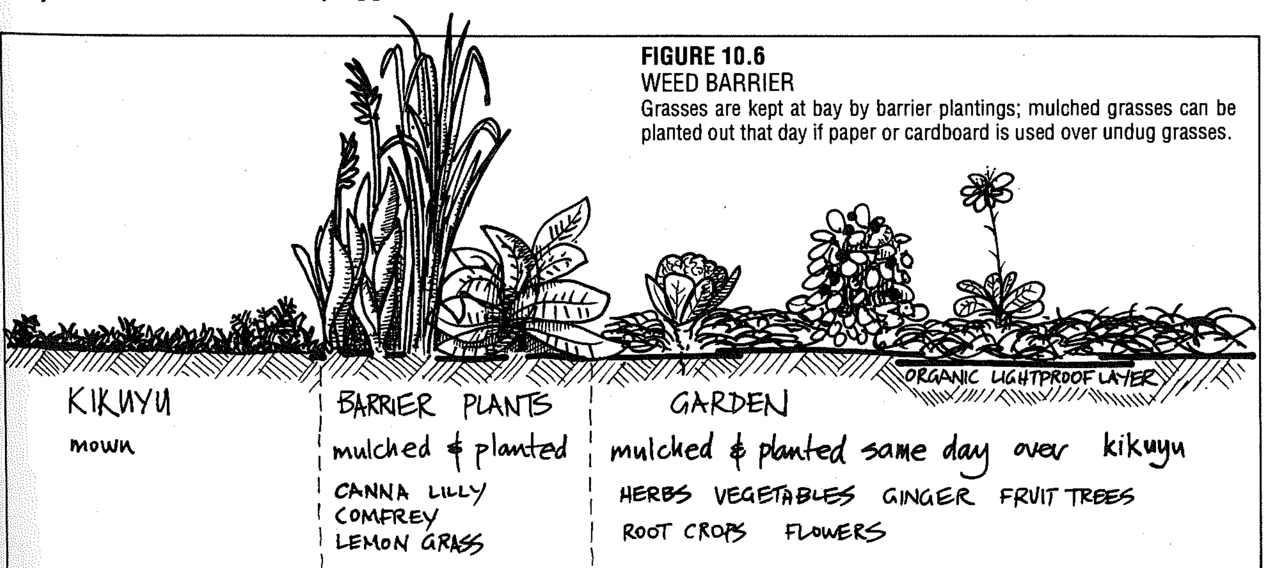


FIGURE 10.6
WEED BARRIER
Grasses are kept at bay by barrier plantings; mulched grasses can be planted out that day if paper or cardboard is used over undug grasses.

Although plastic mulch has a good effect on all crops, it does not add humus to soils, and is therefore not as appropriate to a remote village situation where soils must be built up from wastes and from mulch.

However, every type of organic mulch increases yields, and we should therefore use all available materials for soil restitution. Mulch provision is the cornerstone of tropical home gardens, and green mulch and tree legumes the essential accompaniment of main crops and tree crops.

Special mulches may be used in tropical areas, grown to provide N, P, K (legumes, comfrey, *Pultanea*), and to increase or decrease pH. Pine and legume mulch may benefit the growth of bromeliads (pH 4–5), buckwheat and nut husks serve to raise the pH of garden soils, as do many bark mulches.

For fire control, too, it pays to rake under bamboo and clump canes, and re–route the leaf mulch through animal bedding or poultry strawyards. Branches of legumes and forage trees may also be used in the same way, on their path to the garden.

In the rampant grasslands that replace fallen forests, there is little else we can do than to strip–mow and mulch while trees re–establish. The timing of slashing is important, as seed–free mulch (called second–cut grass) is best for placing around valuable crop. Seed–head mulch should not be placed in gardens or areas where it might be a nuisance. All species of weeds and grasses give weed–free mulch when not in seed. Many useful tree species provide leaf mulch, and so are excellent also for interplanting with crop, for example tamarisk in dry areas, *Casuarinas* in sand, and legumes in all areas.

There is absolutely no excuse for burning any organic wastes in the tropics, as even large logs quickly rot under the onslaught of fungi, termites and beetle larvae. At the same time, logs provide cross–slope barriers against monsoon erosion, until new trees take hold.

Coconut husks have a variety of uses, not the least of which is as mulch for a valued crop such as vanilla orchids. Their one drawback is that they hold small sections of water which will breed mosquitoes, but on many islands they will also be available (with palm fronds) to shred to a first–class mulch of high potash value, to burn and steam to activated (filter) charcoal, or to be used as a solid fuel. Shredded bark and broken shells are ideal mulches for ginger, tumeric, and vines.

I have not found any crop or tree suited to the specific locality that does not grow, produce, and thrive in mulch, nor any widespread pest that grossly affects a total polyculture yield. Ginger, taro, beans, bananas, palms, fruit trees, flowers, yams, sweet potato, melons, etc etc. have been trialed in thick mulches of straw, fronds, nut husks, cardboard, and sawdust. A thick mulch almost totally eradicates kikuyu grass and other persistent grasses. In the field situation, extensive mulching is often impractical, particularly if it is carted in from off the site. However, a pioneer crop of quick–growing tree *Acacias*, bananas, legumes such as lablab, deep–rooting comfrey, and a grove of bamboo and palms will provide continuous mulch for gardens and main crops, fruit trees and valued plants.

Growing in exhausted or poor tropical soils is possible, but the early work of rehabilitation takes hard work, seed, essential fertiliser resources, and a strategy

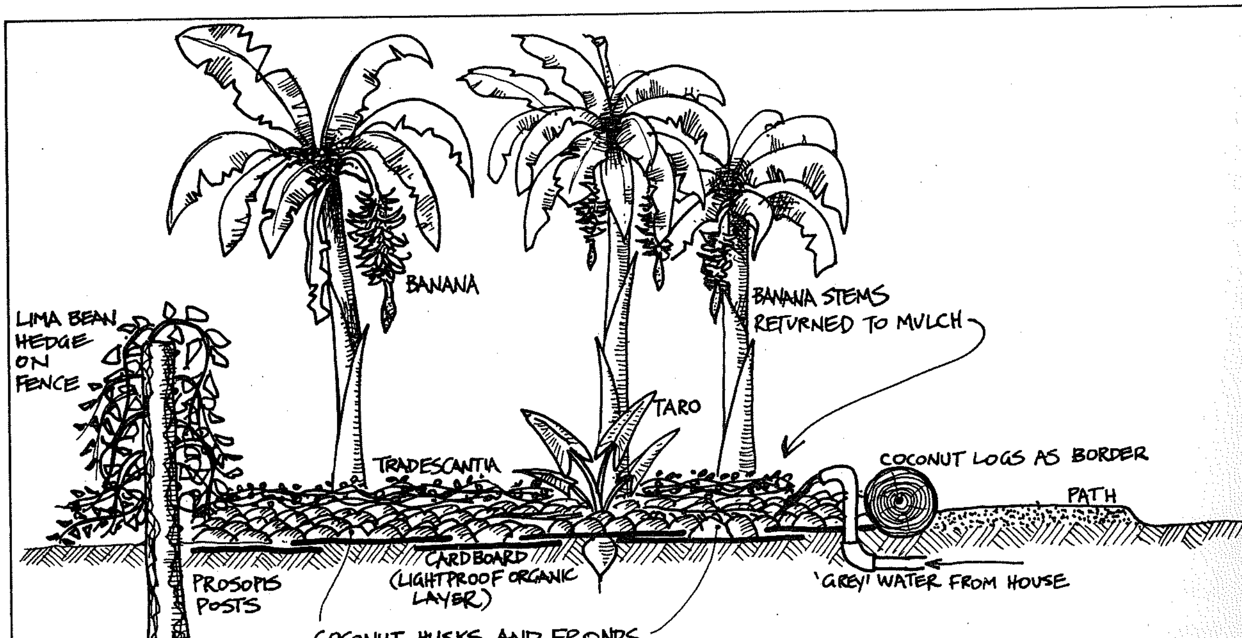


FIGURE 10.7
MULCH IN GARDENS
Held by a log edge, coconut husks and coarse fronds or grasses provide mulch for home gardens; greywater irrigation is ideal.

of starting small and expanding the system at the periphery. Dense planting of nucleus areas plus mulch is the key strategy.

10.4
EARTH–SHAPING IN THE TROPICS

On level ground or gentle slopes (2–8°) in the wet–dry tropics, a series of large contour banks or swales have an excellent soil preservation effect. Coupled with the gradual development of a terrace, the retention of wet-season water, and mulch–providing hedgerow, this ensures a stable situation. Between the main hedges, mulch hedgerow and borders can be developed in crop, or the terraces can be flooded seasonally for irrigated crops (**Figure 10.8**).

On very flat sites (less than 4°), a series of raised mounds or ridges can operate to drain crops in very wet areas, or to impound water for absorption in drier areas. Pits can also be used only where rainfall is less than 76 cm (30 inches), or where soil drainage is good. Thus, cassava, yam, and cucurbits are mounded in areas where drainage is a problem and rainfall intense, and pitted in dry areas or savannah–dry seasons. Pits retain mulch and moisture, as they do in desert areas.

Almost every slope benefits from earth–shaping for soil conservation. Hand–made slope terraces need to be narrower (to 3.5–6.5 m—12–15 feet) than machine–made systems.

Garden terraces on *very* steep humid slopes must be kept narrow, and in sets of 6–8 downslope, otherwise instability may result. Borders can be kept vegetated with trees (**Figure 10.11**).

Classical wet rice and taro terrace has water continuously led into the top terrace of the series, and each has a drain and sump to regulate water level. Fish

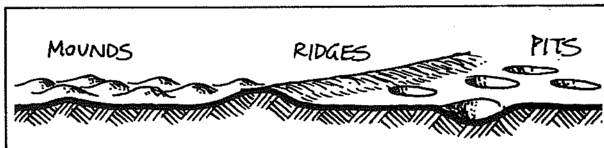


FIGURE 10.9
MOUNDS, RIDGES, PITS
Mounds increase yields of yams; ridges of cassava and sweet potato; pits for taro, arrowroot, and mulch grasses. Terraces need such detailed earthworks.

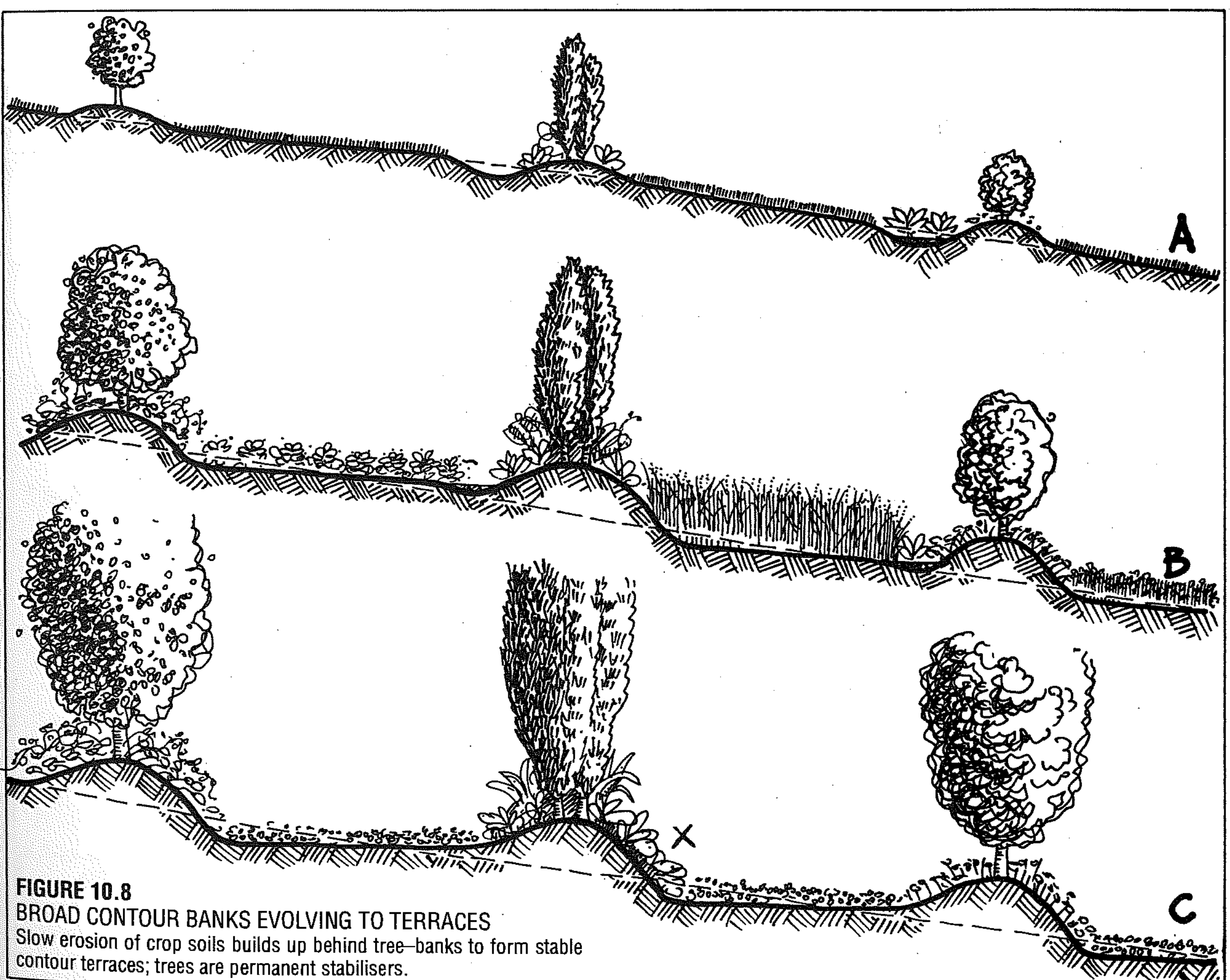


FIGURE 10.8
BROAD CONTOUR BANKS EVOLVING TO TERRACES
Slow erosion of crop soils builds up behind tree–banks to form stable contour terraces; trees are permanent stabilisers.

may be grown in the deeps of such terraces (**Figure 10.12**).

In stable clay or clay–loam soils, terraces not only hold and infiltrate water, but permit mulch application with minimal leaching losses. Where no streams exist to feed the terrace system, DRY TERRACE holds the soil against erosion in cropped areas. Lacking streams, a deep mulch keeps terrace soils moist. Where a stream, or part of a stream, can be led to upper terraces, wet crop such as rice, taro, watercress, kangkong, and water chestnuts (Indian or Chinese) can be cultivated in water–level controlled padi. This is the rich WET TERRACE culture of Asia and Oceania.

Essentials are: about one–half to one–third of the total terraced area should be devoted to *mulch tree crop* providing fodder for livestock or direct leaf and branch mulch to terraces. Ideally, the upper one–third of hills, the very steep slopes of 30° or greater, terrace side–borders, and the outer faces and crowns of bunds (walls) should be planted to productive and mulch–producing tree and ground crop. This not only adds to the terrace stability—many of which have existed in production for up to 5000 years, e.g. the wet terrace cultures of the Ifugao people of the Philippines—but will also provide a local manurial–mulch crop for terrace cultures. Included in such mulches are the crop wastes of the preceeding crop.

Specific Growing Situations on Terraced Lands

- Banks and bunds: the rim of the terraces, and stepped bunds made for tree crop.
- Slope faces and walls.
- On trellis out from bunds.
- In and around ditches and drains.
- On steep (unterraced) slopes.
- The flat area of the terrace itself.

Dry Terrace Crop Species

- Millet: summer or dry periods.
- Dryland rice: spring–summer.
- Barley, wheat, rye: winter and cool periods, spring wheat varieties, *Brassicas*, fava beans.
- Amaranth: summer grains, spring greens.
- Quinoa: summer grains.
- Rape/mustard: winter oils and oil seed.
- Lentils, peas: intercrop and nitrogen fixing grain legumes.
- Grams and pulses: intercrop and nitrogen fixing.

Fodders

- Tagasaste, banna grass, comfrey, *Leucaena*, crop wastes and straw.

Garden Terraces Near Homes

- Banana, papaya, melons, chilies, peppers, cucur-

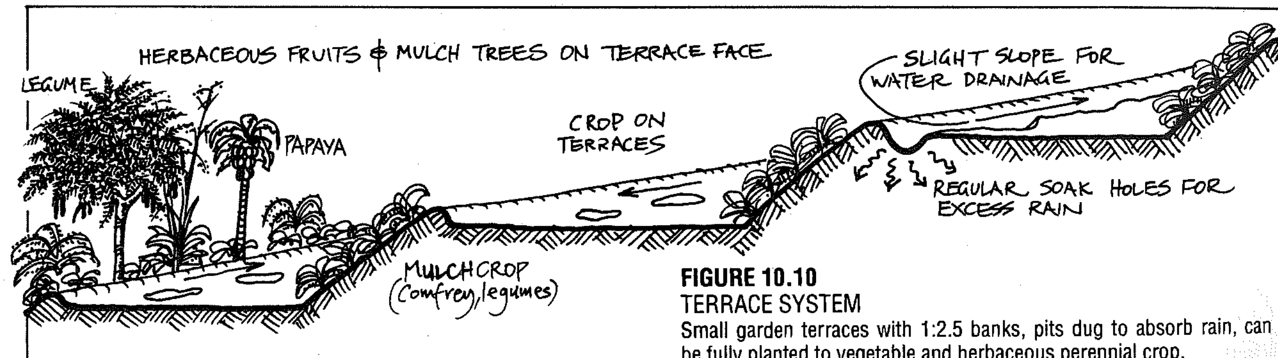
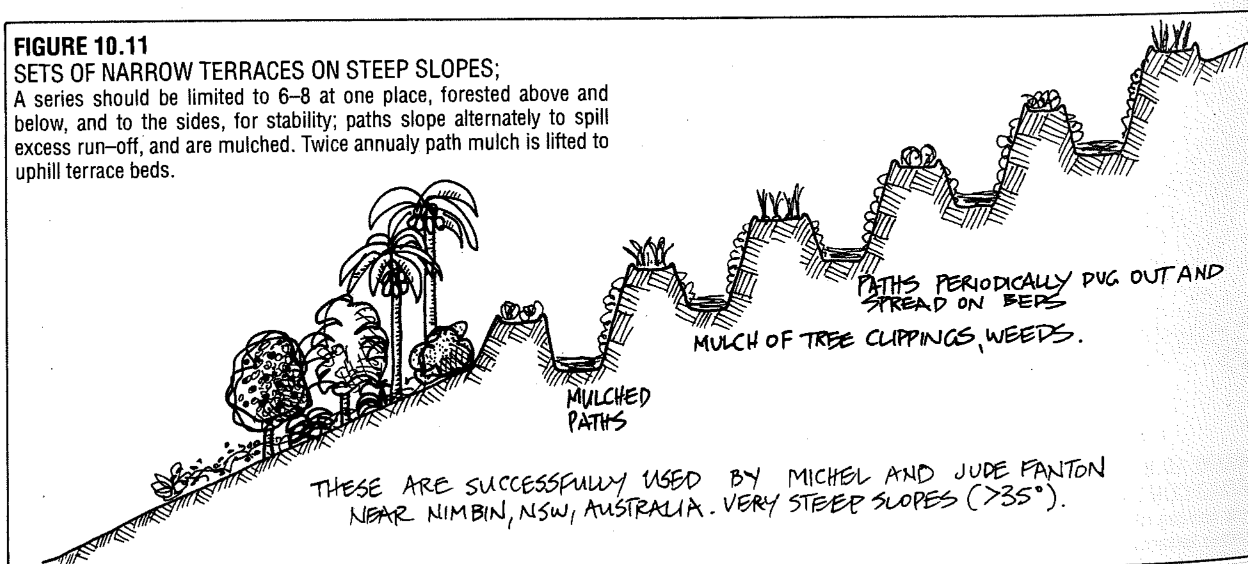


FIGURE 10.10
TERRACE SYSTEM
Small garden terraces with 1:2.5 banks, pits dug to absorb rain, can be fully planted to vegetable and herbaceous perennial crop.

FIGURE 10.11
SETS OF NARROW TERRACES ON STEEP SLOPES;
A series should be limited to 6–8 at one place, forested above and below, and to the sides, for stability; paths slope alternately to spill excess run–off, and are mulched. Twice annualy path mulch is lifted to uphill terrace beds.



rbits, maize, beans, sugar cane, cultivated green–crop *Brassica*, edible *Chrysanthemum*, edible *Hibiscus*, rosella, horseradish tree (*Moringa*), coconut, mango.

Vine Crop Off Bund Faces

- Chayote, cucurbits, beans, passionfruit, kiwifruit.
- Bamboo on borders provide trellis material, as do rot–resistant timbers.

Mulch Crop and Fodders Above to the Borders

- Tree legumes, banna grass (*Pennisetum*), lemongrass, Vetiver grass, comfrey, bamboo and palm fronds, *Aleurites* spp., *Cinnamonum* spp.

Slope Stability

- Contour strips of Vetiver grass, lemongrass, banna grass with tree legumes not only replace contour ridges but trap soil particles, and is a cheap way to "terrace", even on steep slopes. These strips provide mulch for trees and intercrop (**Figure 10.13**).

Essentials and Variations on Terrace Systems

- Borders; and uphill, steep–slope, forest crop planted and selected for mulch value and fodder, or:
- Animal sheds (ducks, pigeon, poultry, pigs, bees) over top terraces; manure on a "washdown" system.
- In–crop mulches such as beans, *Azolla*, clovers.
- Staggered, short sets of terraces for steep slopes and high rainfall, compared with more continuous and longer series for winter–dry irrigated terrace.
- Deep areas in terraces for fish/crayfish/ shellfish refuges.
- Vines over all or part of the terrace to aid such crops as taro.
- Bunds planted in clover, beans, comfrey, lemongrass, fruit crop.
- Splash stones or splash plates for falling water; methods of draining terrace.
- Border drains in terrace to keep soil dry for mid–season crop.

10.5
HOUSE DESIGN

Optimum comfort levels for people are at dry–bulb temperatures of 20°C (68°F) in still air (winter), and 25°C (77°F) in summer, subject also to individual preferences. Above relative humidity levels of 40%, we effectively add 1°C to dry–bulb temperature for every 4% increase in humidity. As average summer humidity in wet–dry tropics commonly exceeds 50%, and long periods of humidity of 70% or so are experienced, there are times when sensible temperature exceeds 30°C (86°F), and heat stress results.

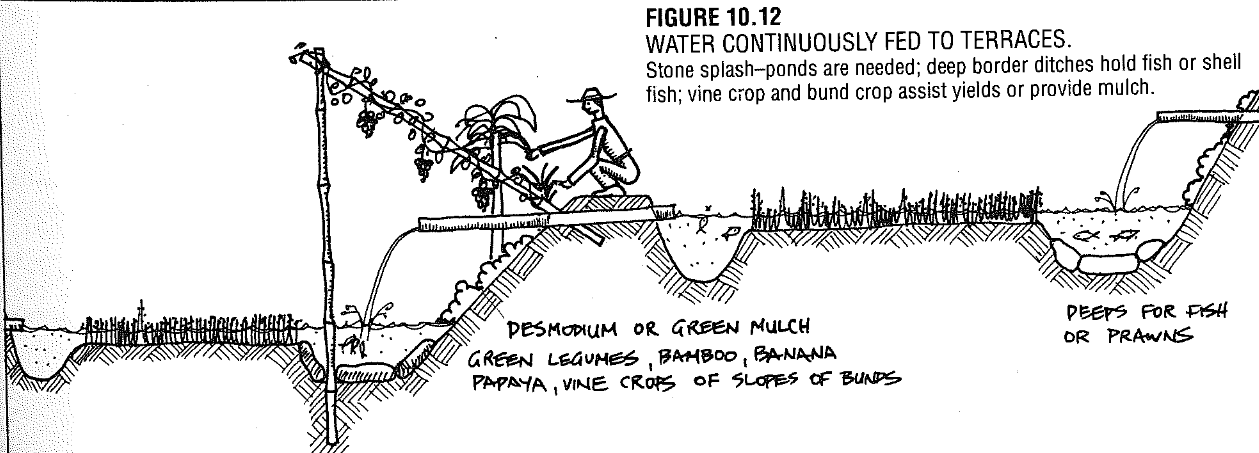
In homes, a useful indicator is a wet–bulb thermometer, where the mercury bulb is kept damped by a cotton wick drawing from a beaker of water. Below 18°C (65°F) wet–bulb temperature, we can remain fairly comfortable.

Factors that accentuate heat are nearby radiant surfaces and lack of air movement. For a nearby radiant heat source (wall or pavement) that exceeds 38°C (100°F), we can add 1°C (per degree radiated) to the air temperature, and conversely, we can subtract 1°C for any air flow above 1 m/second.

Evaporative cooling in dry air greatly reduces heat, but as the high humidity periods of tropics do not enable us to cool by sweating, we must therefore use every strategy available to de–humidify air (mainly by cooling), to cast shade, to develop cool surfaces, and above all to induce cool air currents in houses. Overshading trees, attached shadehouse, white exterior and interior surfaces, and clear–path breezeways are essential design strategies both in equatorial and sub–tropical climates.

In many continental subtropical locations, we are faced with dual problems of quite intense winter cold, with some frosts (and rare snows), and very humid and hot summers. Thus, the sort of house we need to build has several unusual characteristics, and needs perhaps more careful planning than either equatorial houses (where reducing heat is the only problem) or temperate and boreal housing (where providing heat is the only problem).

FIGURE 10.12
WATER CONTINUOUSLY FED TO TERRACES.
Stone splash–ponds are needed; deep border ditches hold fish or shell fish; vine crop and bund crop assist yields or provide mulch.



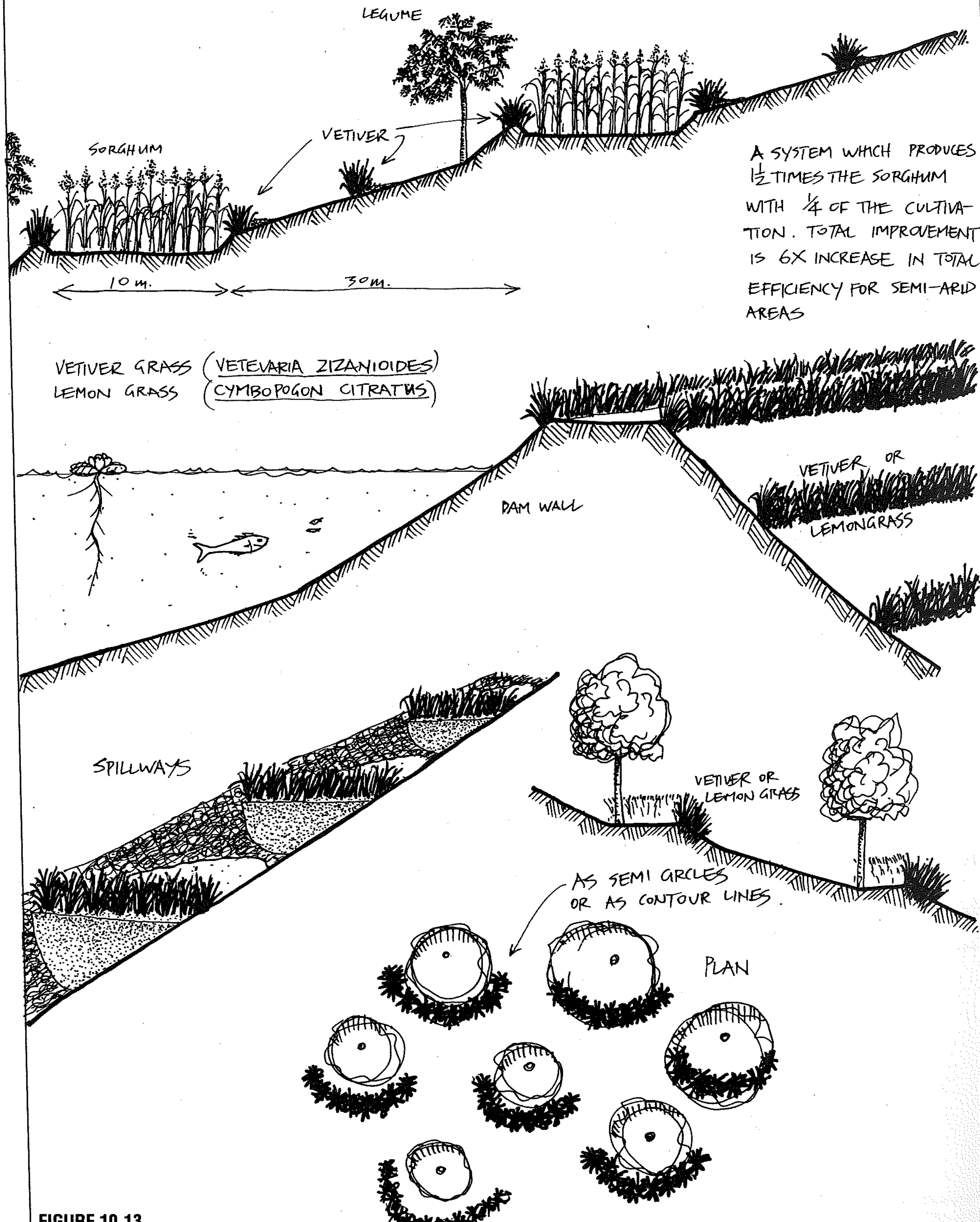


FIGURE 10.13
VETIVER OR LEMON GRASS STRIPS
provide cheap erosion control on contour or bund stabilisation; both these grasses clump readily, have few seeds, provide mulch, and hold soil movement.

The subtropical house needs to both heat and cool. For heating, it needs to have an insulated slab floor or trombe wall, and for the cooling system it needs induced or forced cross–ventilation from a cool or shaded area to an updraught area.

The secondary effects of high humidity range from the merely annoying (salt will not pour) to far more serious effects (clothes, food, film, and books mildew). Thus, we face two sorts of problems in house construction:

- Human comfort.
- Safe storages; for these we need both cool and warm storages, but both need to be *dry*.

Human comfort is greatly aided by these factors:

- SHADE: Light and heat are both excluded as incoming radiation in shade. Shade is particularly critical on massive walls or over water tanks close to homes.
- TRANSPIRATION: Plants can assist cooling by transpiring. Partial shade helps this factor in understory species except in extremely wet conditions.
- COOL BODIES: Large heat resevoirs used as water tanks and relatively cool blocks of (shaded) stone, concrete, and mud brick absorb heat from the air and from warm bodies. Conversely, hot radiant bodies adversely affect us.
- AIR FLOWS: Even low air flows from shaded areas greatly aid both transpiration and evaporative cooling. To create such air flows we need to develop both relatively hotter and colder air sources and to provide a

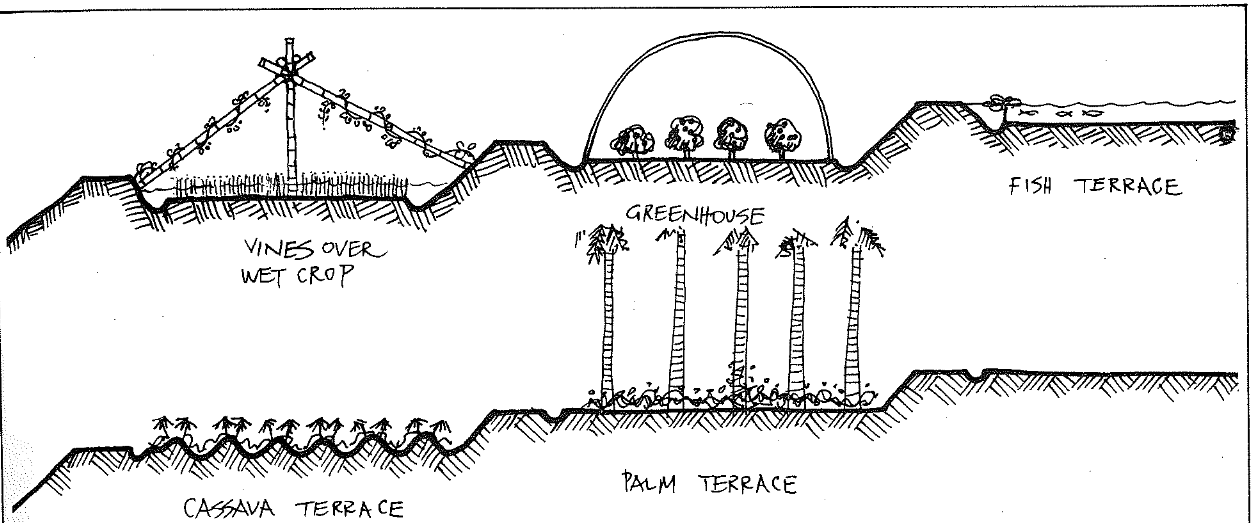


FIGURE 10.14
VARIATIONS ON TERRACE CULTURE.
Wet terrace (padi), fish crop, shadehouse or grow–tunnel, ridge crop, palm, and grain culture vary production and stabilise terrace cultures; alternate dryland and wet (padi) crop suits summer–wet sub tropics.

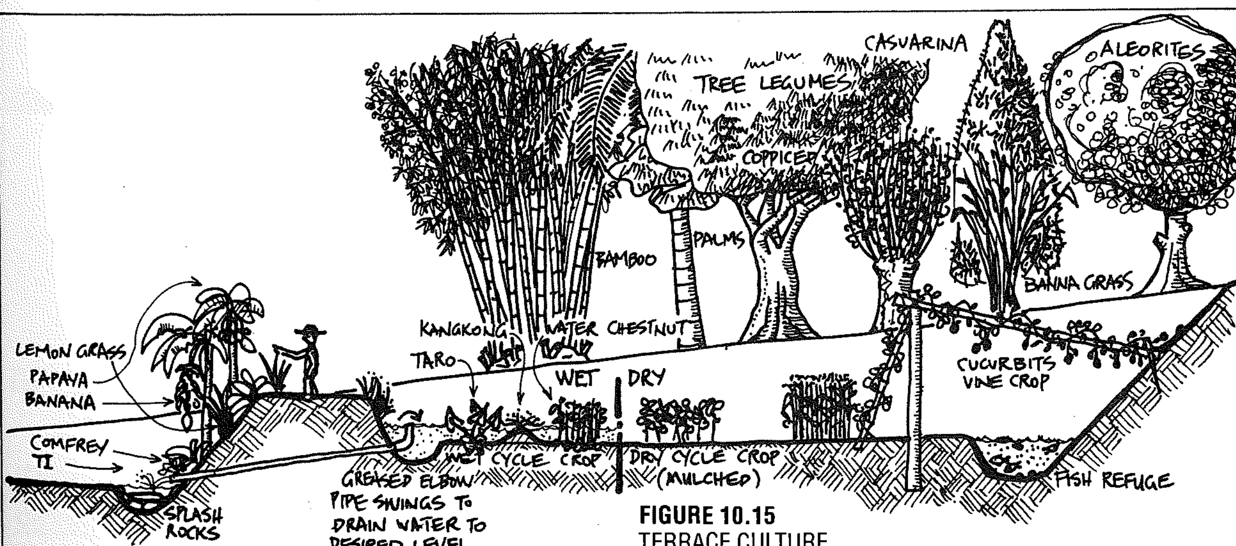


FIGURE 10.15
TERRACE CULTURE
The sloping side–bank here is shown planted to ideal mulch trees, cut or coppiced to enrich terrace crop production. Drain pipes are adjustable to dry out terraces.

cross–flow airway. Even a fan, simply stirring the air, aids in human comfort.

• REMOVING HEAT SOURCES: All massive cook–stoves and hot–water systems are best placed in a semi–detached kitchen in the tropics. Commonly, these are reached via a vine–covered shade area, are themselves shaded by palms or trees, and have wide eaves and ceiling vents for hot air escape.

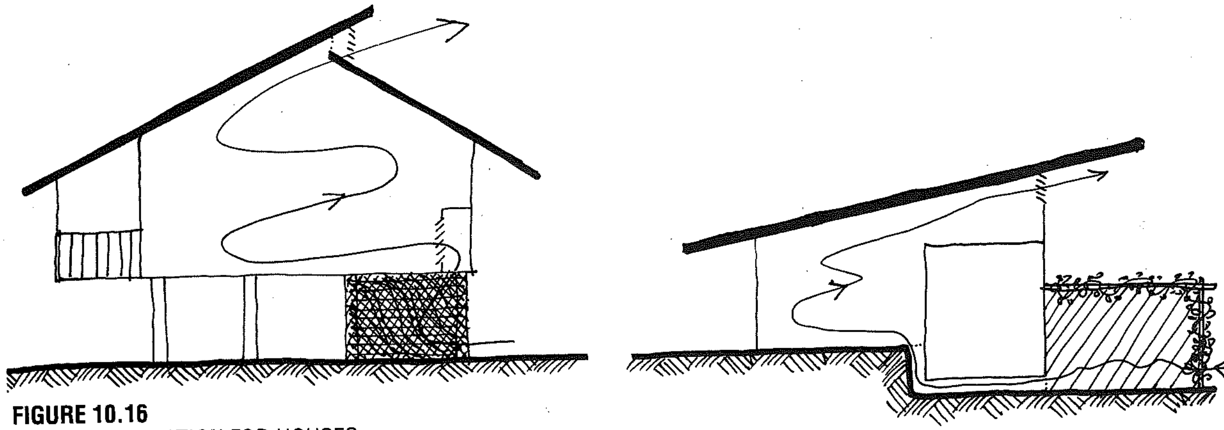


FIGURE 10.16
CROSS–VENTILATION FOR HOUSES
Vented ceiling slopes allow hot room air to escape, and cool trellis air to enter.

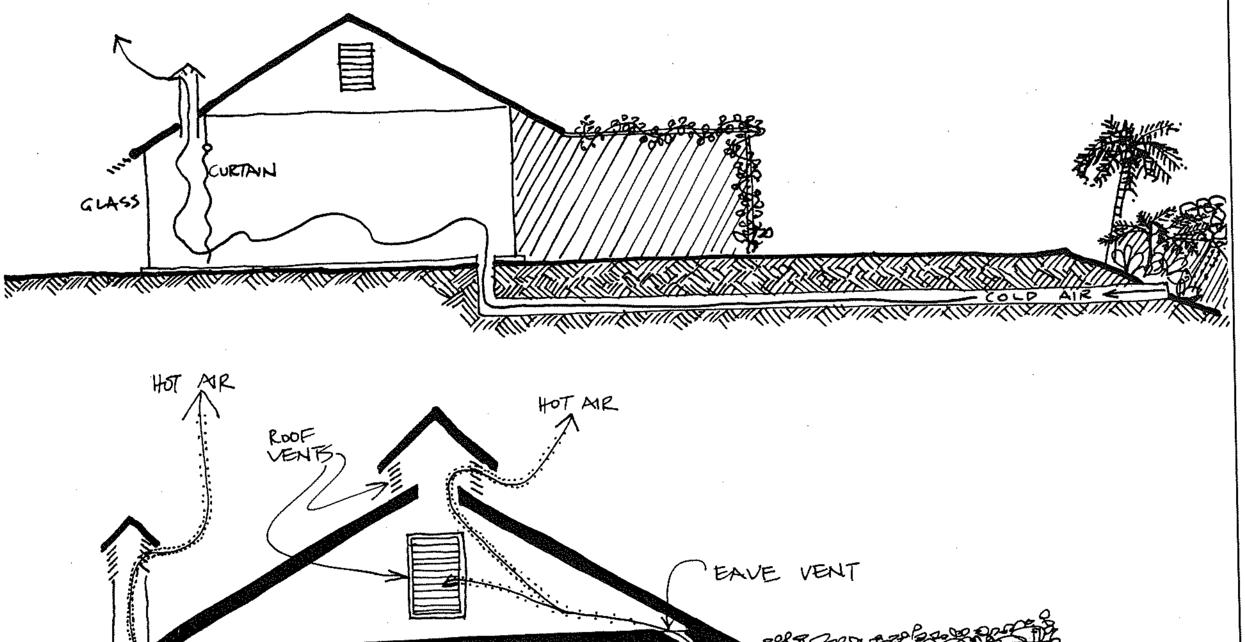


FIGURE 10.17
COOL AIR FROM SHADEHOUSE AND BURIED PIPE.
A 0.5 x 0.5 m tunnel 1 m deep and 20 m long sloping to the outside intake to de–humidify and cool equatorial air, with a solar chimney to draw air through the house.

Heat can be used via metal roof areas, hot–water storages, and attached glass–houses or solar chimneys to vent hot air and create updraught, which in turn provides a heat engine to draw in cool air. The essentials of good cross–ventilation are that the flowing air has a simple pathway to follow (no unnecessary corners to turn), and that large vents are used to allow a good volume of air through workrooms and storage areas (**Figure 10.16**).

Probably the best cooling systems in tropical houses are those which use a hot roof or metal chimney to draw in cold air from earth–cooled underground tunnels or pipes. As this cool air is dense, it will naturally flow downhill or sink to lower levels; this cool air can be drawn into houses via a positive exhaust system, or actively fannned into rooms.

To cool a pipe and lead off the heat continously, we need to construct a trench 1 m deep and 15–20 m long cut in the earth, drain off the condensed water (ideally making it self–draining to a lower slope), and provide this trench or pipe with a sloping floor. The intake end can be box–screened to keep out mice, and shaded by plants. Outlets can be floor grills or a louvred "cupboard" opening to the pipe or pipes in the trench (**Figure 10.17**).

Natural cross–ventilation can occur if a well–sealed room has a roof vent or chimney to create an up–draught. Some forms of air scoop may help this process

The cold tunnel solution is very effective, and can be used together with evaporative cooling in desert housing, but it is also expensive, and difficult to fit to an existing house. For this reason, many homes can be sufficiently cooled by the use of vertical shutters acting as air scoops—a satisfactory solution on subtropical tradewind coasts. Or a shadehouse can be added to the poleward side of a house and cross–ventilated to a well–vented GREENHOUSE on the sun side of the building.

BASIC ESSENTIALS OF THE EQUATORIAL HOUSE

Some essentials of truly tropical housing (no cold season) are:

Site Choice

- Orientation is to *prevailing winds*, not to the sun. Cooling is by cross–ventilation.
- Shaded valley sites greatly aid cooling and shelter.
- Induced ventilation is essential, achieved by siting in palm groves or overshaded by trees, which should be permeable to wind at ground (house) level. Palms and trees can be pruned up the trunk.
- Site sheltered from hurricanes, *tsunami*, and vulcanism, sited on stable soils that resist mudflow in heavy rains.

House Design

- Walls white or reflective, overshaded by wide eaves and palms or trees.
- Heat sources such as stoves and hot water systems detached from the main structure (e.g. outdoor kitchens).
- Wall–material light, even permeable to wind (woven matting and mosquito screens).
- Mass, if any, internal to rooms, smooth and white–painted. The whole house can be of light construction on the outer walls.
- *Vertical* louvres and window shutters aid in

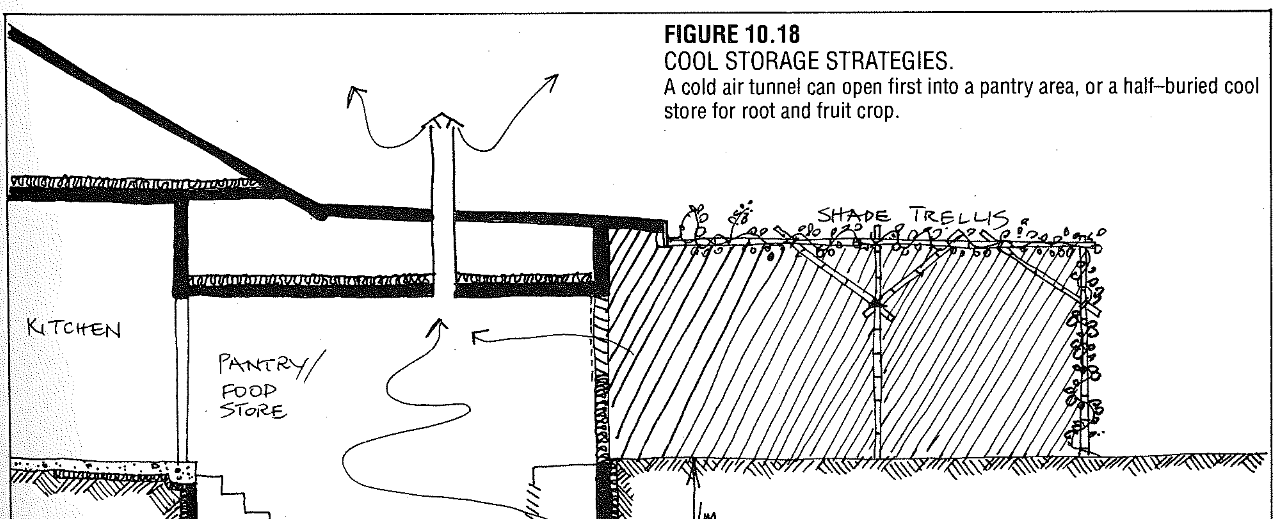


FIGURE 10.18
COOL STORAGE STRATEGIES.
A cold air tunnel can open first into a pantry area, or a half–buried cool store for root and fruit crop.

cross-ventilation.

- In hurricane areas, a strong central core or refuge may be needed, or an earth-bank shelter raised to protect the house; cellars should be entered above ground due to flooding danger in hurricanes, or well sealed against flooding.
- Very strong cross-bracing, deep ground anchors, and strapped timbers may be necessary if powerful winds are known to the area. Large bamboo groves placed to the windward will bend to the wind without breaking, protecting the house.
- Where thatch or tile is impractical, use a vented sheet metal roof. In this case a thin (12 mm board) ceiling is necessary, and soffit lining can be of permeable netting or screened to allow an air flow to the roof space and thence to the exterior via high roof vents.

10.6
THE TROPICAL HOME GARDEN

SEASONS: The wet season is the "hungry gap", where plants are growing, but too young to harvest. Early in this season the soil is soft enough to plant and establish trees, but plants must be well-timed as the dry season is long-lasting. Planting too late is to risk drought before ripening of the crop. Vegetable crop is started at either end of the wet season. Water storages (Chapter 7) are essential, no matter how modest, for garden, tree crop, and diversity in yield. Moulds, mildews, and root fungi are encouraged by humidity, and it is best to use resistant plant varieties or root-stocks.

SPECIES: Mango, papaya, sapote, banana, limes, coconut, cashew, macadamia nut, breadfruit, mound-planted avocado and pineapple, durian, and so on are the garden and orchard framework, as are any productive palm crops. Large legumes such as *Inga*, *Gliricidia*, *Leucaena*, *Cajanus*, and so on are essential interplants.

In the vegetable garden, yam and sweet potato yield better than, or in place of, potato. Adapted small-fruits and tomatoes of wilt-resistant strains grow well. Amaranth is a good green and grain crop. Lima, velvet, and *Dolichos* beans trellis on tree legumes. Forage and ground legumes provide green mulch and help suppress grasses, as do comfrey and lemongrass. Chilies, peppers, and the range of tropical vegetables are preferred to temperate species.

Bamboos, balsa, teak, palms, and mahogany provide structural and craft materials, rattans can be encouraged along waterways and in mangrove edges. Oil palm, jelly palm, *Bactras*, *Maurantia*, salak palm and doum palm provide trusses of useful fruits.

PESTS: Large insect pests (locust, cicadas, sucking bugs) are plentiful; guinea-fowl or chickens on range are some defense. Native rodents and pigs can be damaging, and pythons rather than foxes take poultry. Termites and ants largely replace worms in soil-building, and buildings must be constructed to resist them. Geckoes in houses eat many insect pests, as do wolf spiders.

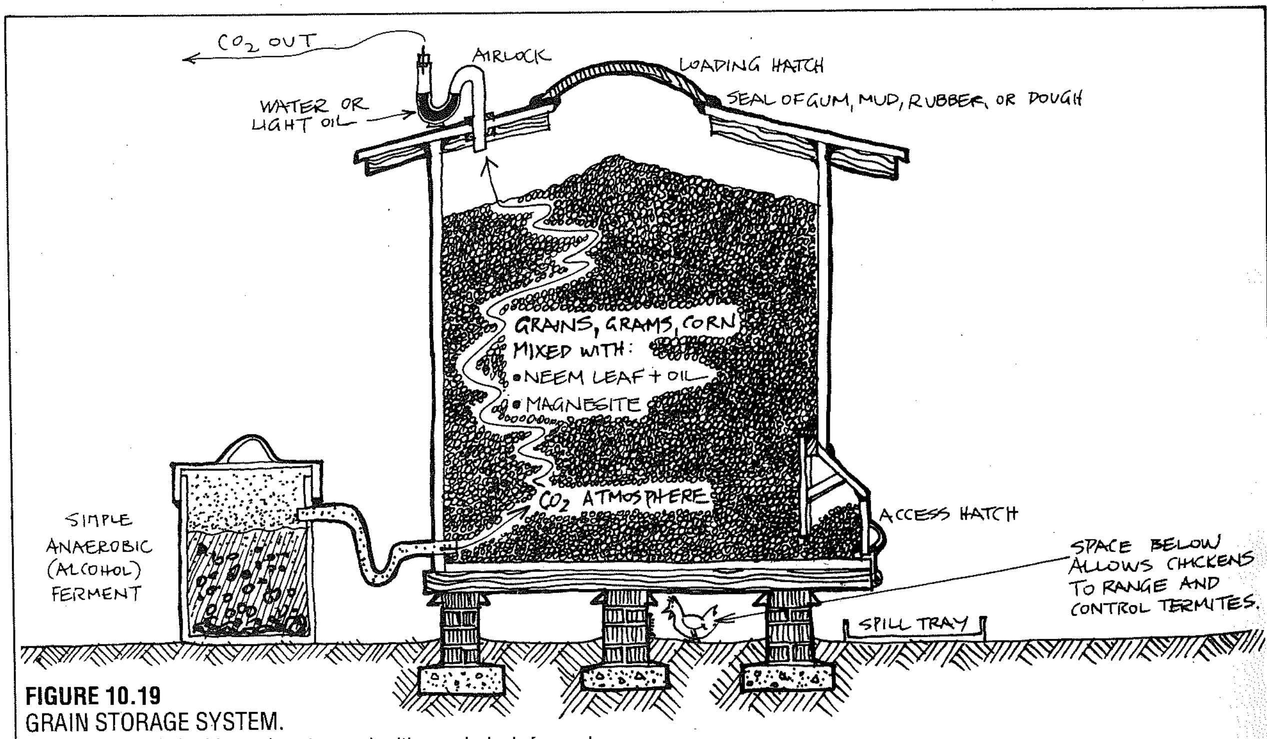


FIGURE 10.19
GRAIN STORAGE SYSTEM.
With its lid sealed with mud or tar, and with an air-lock for carbon dioxide escape; a nearby ferment provides CO_2 which kills pests. Store is raised on stones to allow chicken control of termites.

DOMESTIC ANIMALS: Pigeons and bees are most easily protected from predators by elevation on pole structures, or over shallow ponds. Guinea fowl, francolin, pheasant, and bantams provide essential foraging and insect control services. The guinea–pig aids small tree establishment as they "chip" the base of young grasses, and small pigs of Taiwanese strains provide orchard–fruit garden scavenging duties. Waterfowl and aquatic species add yields to water storages and assist in grass control.

HURRICANE DAMAGE: can be limited by raising large earth banks, selecting valley garden sites, screening plantings with bamboo groves, establishing a general tree canopy through garden and plantation, or a combination of these strategies. Oversize swales aid wet–season water run–off control and diversion to storage.

SPECIALIST CROP: There is a wide range of specialist crop potential, from rubber (*Hevea*), betel–nut, chalmougra oil, and chicle to essential oils and medicinals. Many are suited to primary processing in remote locations, or conversion to commercial–quality end–products. The high value of processed product enables smallholders or cooperatives to pool research and processing facilities, and to select high–yielding varieties.

INTERPLANT: As well as the essential legumes, a scatter of *Banksia, Casuarina, Gigasperma calaspora*, and *Pultenea* with their mycelial associates will fix phosphate and return it via leaf mould. Several plants "pump" sugars or carbohydrates into soils, while leaf–sucking insects and scale insects exude sugars

FIGURE 10.20
EARTH–SHELTERED HURRICANE HOUSES.
Based on Japanese typhoon–proof coastal housing; bamboo groves provide a flexible wind barrier. Earth mounds. Houses well–braced and anchored.

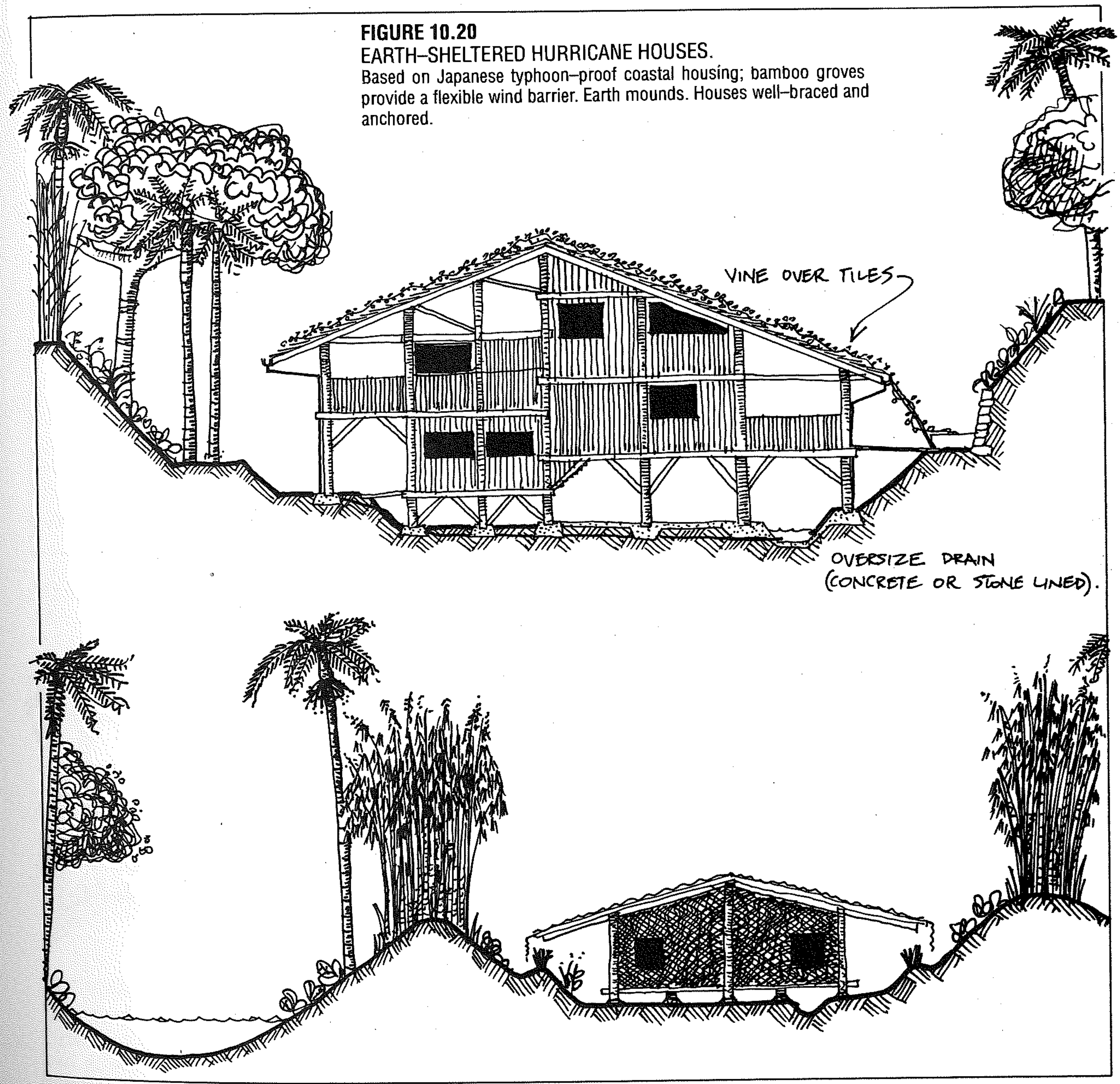
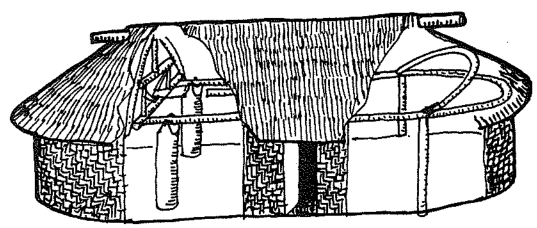
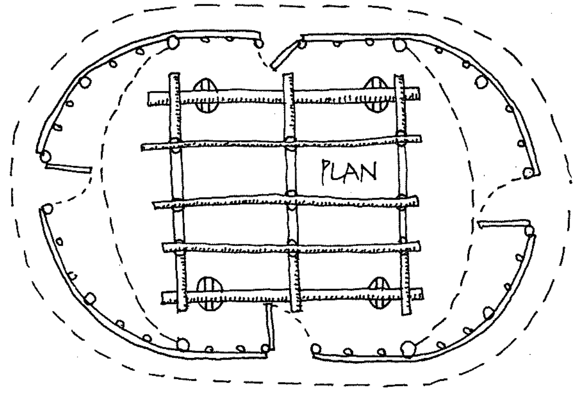


FIGURE 10.21
EQUATORIAL HOUSE.
Based on the Fijian buré. Earth–sheltered and well–fastened (traditionally by complex rope cross–binding) this house is ideal for hurricane areas, cool living, strength, cheapness, and uses only local materials.





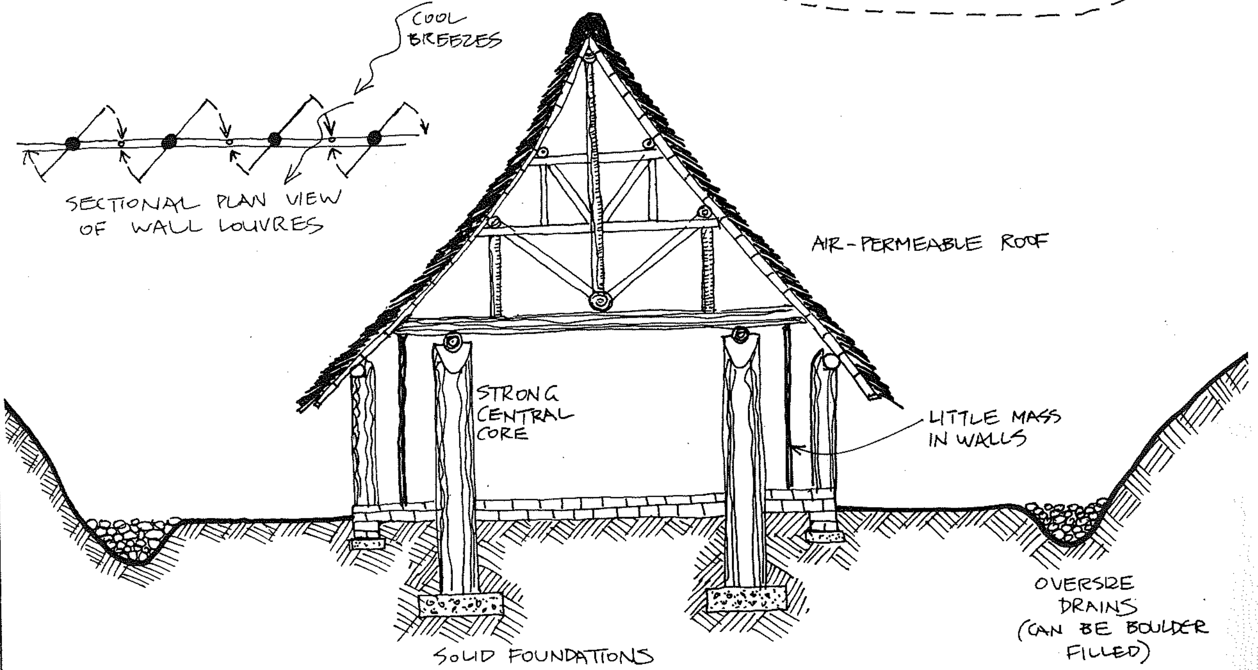


FIGURE 10.22
HURRICANE GARDEN.
Sunken between earth berms or in natural sheltered valleys; palm and bamboo to seaward. Heavy emphasis on root crop for emergency food, fast regrowth. House well–braced and anchored, low profile.

from stems. Dilute molasses or cane and sorghum sugar juices and stems also activate soil fauna. Marigolds, neem tree leaves or berries, and pyrethrum daisy control soil pests and provide insecticides or water insect control. The neem tree is often planted to overhang ponds, so that the berries that drop control water–flies and mosquitos.

Established tough grasses of the savannahs resist gardens, and need to be mulched or overshaded with tree canopies. Essentials are:

- To mound or raise garden beds for good drainage in the wet season.
- To use mulch and mulch–tree species to create topsoil for gardens.

Where logs exist, they make ideal garden bed edges to hold mulch and soil.

Gardens have been devised for many tropical areas, usually containing the following:

- Designed for full nutrition for an average family.
- Water conservation and safe water disposal (hygiene) a necessity.
- Species chosen to suit local cultural preferences.
- Sufficiently varied to survive reasonable climatic change, or seasonal irregularity.
- Protein sources, livestock; their forages, or grain/legume replacements for meats.
- Water routes and use.
- Basic foods or staples
- Fresh vegetable and fruit for vitamins, minerals, varied uses.
- Some fuels, medicinals, flowers.

The elements in **Figure 10.23** are those that make up the house structure itself, and those that make up the garden, hedgerow, livestock and path access structures. The best way to use this section is to read it through very carefully, study the plans and diagrams, and then improve it, or better it to fit to a specific site.

THE HOUSE

Room size and number is adjusted to family size, but is basically a simple, easily–heated and cooled structure, preferably on slab or raised pise floor, and preferably edge–insulated. The induced cross–ventilation acts to cool and heat as per **Figure 10.16**. In addition, vertical sashes or shutters to each room help to scoop air in.

In hot periods, the main living area is outside rear, or under a similar porch trellis to the front if the people prefer to be seen from the road (as is the case in most close–knit societies). The side trellises are seen in **Figure 10.17**. Materials can be local, as can any insulation. Glass is needed, as are some pipes or drains of stone, and a tank.

THE GARDEN

How the Garden Works (See **Figure 10.23**)

First, it accepts all water and wastes of use. Only plastic and glass or metal are not used, although some cans *may* be buried for slow zinc and iron release). Second, it provides most mulch and a lot of fodder or forage, which when bulked out by house–scraps should feed rabbits, guinea pigs, some poultry, and even fatten a small pig. Next, it is very accessible and well–designed on a need–to–visit–and–tend basis. It is also very natural in appearance and function. If no septic tank is present, a dry toilet will do, and the manure can be put under trees (in pits). Even "toilet paper" can be built into the hedges (E) (*Nicotiana* is great, as is *Leucaena*).

Accessories

Hot water for showers can be achieved by a hot–water collector or at least a coil of black pipe on a roof or bare area. With a couple of oil lamps or a photovoltaic array, a solar oven on castors, an efficient cooker, and a small solar food drier, life should be fairly cheap and healthy. Adventure can be sought in teaching neighbours how to do it, writing novels, or joining an adventure–camp group—or even a permaculture group (they behave *very* diversely!)

GANGAMMA'S MANDALA

In Taiwan and the Philippines, small intensively–planted home gardens are planned to feed a family of five all year. I have added to these designs my own permaculture "least–path" layouts to give a very concise and effective model of sustenance garden design for tropical and subtropical regions. These can also be adapted to temperate regions, using suitable species. The overall pattern can be altered to fit almost every site form, but is presented here as a flat site pattern. Although the building of such a garden is fast and simple, its design is sophisticated.

The whole design owes much to the work of the East–West Institute in Hawaii, and the Samaka gardens of the Philippines, but the layout is purely permaculture. I have named it "Gangamma's Mandala" after one of our Karnataka (India) permaculture design graduates.

Steps in the process are:

1. At the centre of a 100 square metre (1075 square foot) or larger area, describe a circle 2 m (6 feet) across and excavate the topsoil (or subsoil) to a dish shape, ridged on the perimeter, and about 0.6–1 m (2–3 feet) deep from hollow to rim. This is the banana/sweet potato/papaya circle garden, as per **Figure 10.26.1**.

The whole circle is then covered with wet paper or wet cardboard, banana leaves, or any mulch material, and the hollow is filled (or over–filled as a dome) with rough mulch of short logs, coarse twigs, hay, rice husks, and sawdust or indeed any humus–creating materials. A little scatter of manure, ash, lime, dolomite, or fertiliser can be added. If stones are available, bank them to the outside of the rim.

The rim is then planted to 4–5 papaya (a tall variety), 4 or so bananas (dwarf types), and 8–10 sweet potato. If available, yams or taro can be placed *inside* the rim. Later, beans can be planted to climb the papaya and banana stalks. In the banana circle, we can place a grid

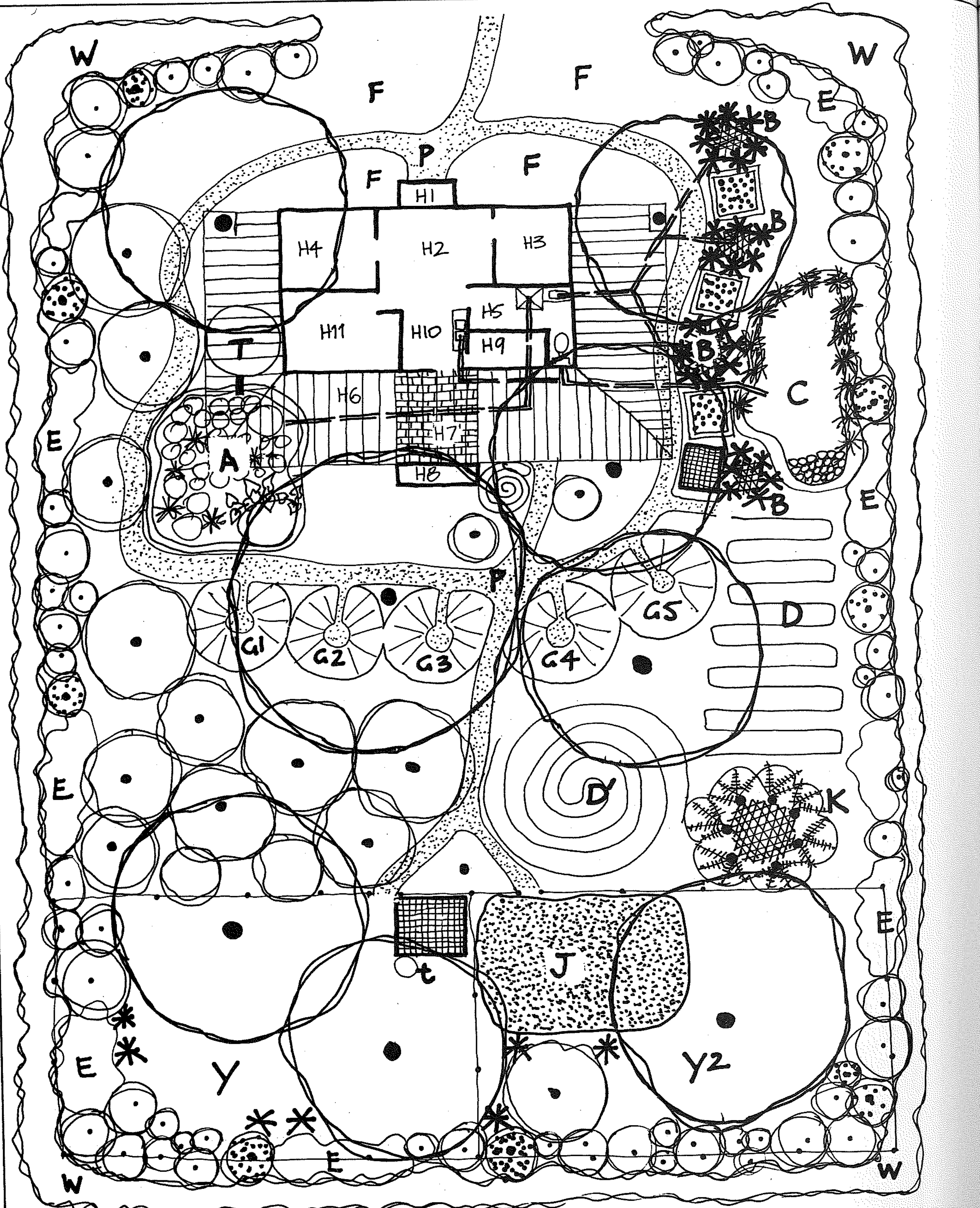

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FIGURE 10.23

ELEMENTS OF A TOTAL DESIGN FOR A GARDEN.

Based on a Brazilian design by Margrit Kennedy and the writer; climatically appropriate house of local brick and tiles amortizes in 4–7 years if a garden is developed. All water is caught or directed to gardens.

H1: An entry; in the subtropics this is a glasshouse, fitted with a wide ceiling vent and drawing cold air in from **H6**—the shadehouse. Note the straight-through airway via living area (**H2**) and winter kitchen (**H10**).

H3, 4, 11: Bedrooms and study/library if needed or possible. All open off or into the central kitchen (**H10**)/living axis (**H2**).

H5: The bathroom/toilet. From here, shower water goes to the "wet" area of garden (**A**) or to mulch/ forage crop (**E**); toilet and sink water goes always to (**C**). Handbasin water goes to (**B**), banana circles.

H6: Is the shadehouse, which can extend around three sides of the whole, and has entries, trees (or their trunks) in it, minor trellis resting against it, and a crop below.

H7: is the part–paved area of the summer kitchen, and **H8** the outdoor cooking stove and bulk–cooking stove, the ashes of which go to **A**, **C**, and the garden.

H9: Mudroom/pantry off the kitchen, with outside basin/sink for primary vegetable processing.

Table scraps go to livestock *or* below mulch in boxes (**B** series) of the garden; sweepings to mulch.

T is the tank, catching roof water. There is a small tank (**t**) on any animal shed. The tank can also be filled from a reticulated water system (on a float–valve). All tank overflow goes first to (**A**), the wet garden bed, which is in part under the house trellis, in part in the open. There is a path (**P**) around the whole house and to the outdoor kitchen, animal house, etc.

The garden has the following main elements:

A is a wet food patch with earth bank edge (detail **Figure 10.24**). This receives clean water and grows wet crop, e.g. taro, rice, kangkong, watercress, Chinese water chestnut, etc. The bank is planted to dry staple foods, e.g. yam, sweet potato, cassava, etc., which benefit somewhat from the wastewater. Some of this crop is under partial shade, which taro appreciates, as do some other sub–aquatics.

B are banana circles (see **Figure 10.26**). They can also be papaya circles or mixed papaya/banana/pigeon pea/tomato/yam circles, or any such combination. They are watered from the hand basin and kitchen sink and mulched inside from the hedge (**E**).

C is the "dirty" water patch (**Figure 10.25**). It contains *no direct food plants* and *no root crop*, only vigorous, damp–tolerant, manure–tolerant green forage crop, e.g. comfrey, banna grass, lemongrass, legumes. These are regularly cut and removed either to the animal pens as green feed *or* to the little potato boxes (**B**) *or* to the garden beds (**G** series). The area is sunken and surrounded by a bank on which can grow pigeon pea, papaya, banana, or all of these and more.

D & D' are avenue crops of maize, corn, or some main crop of value. Two layouts (spiral and zig–zag) are shown (detail **Figure 10.27**). They consist of self–mulched and stable intercrop systems such as maize/ beans, yam/beans, cassava/beans, or melon/beans, with plants of *Leucaena, Gliricidia, Sesbania*, or some such productive legume as a fixed hedge. Sticks from these go to the fire; ash returns to the garden. Hedge clippings from **E** or exotic mulch (paper, carpet, wastes) can be put on these beds.

E is a low, raggedly–trimmed hedge of forage–mulch species, and is used for privacy, as a windbreak, and a sometime food source. Just *outside* it is a very dense weed barrier (**W**). In two places this hedge is *inside* two chicken pens (**Y** and **Y2**). Where there are "spots" it means a few well–chosen clumps of sympodal, edible–shoot, solid bamboos form part of the hedge. These are partly for food, partly for mulch, partly for the trellis repairs.

F is the front yard of traditional or showy flowers, if the culture demands it. It has a few basic medicinals, pleasant scents, a fibre plant or two (to help the trellis), a few ornamental food plants (cacti, agave), and is rarely watered so all plants there are hardy.

G are "keyhole" garden beds (**Figure 4.10**); these can be extended to either side of the house for large families, and more to the rear if necessary. All the preferred vegetables, especially greens, are here. The nearest bed to the kitchen has the usual bulk culinary herbs, but some of these are also on the small spiral herb bed (**Figure 4.34**) beside **H8** (the outdoor stove), and a few wet–area herbs are in pots under the trellis in the A pond (mint). Some rare dry–area herbs may be at or near the front door (**F**).

The two trees near **H8** are a lemon or lime and an allspice or caper tree (shrubs, really). They placed near the house as they are the most–used trees in the system.

The rest of the **G** beds are carefully–planned seasonal vegetable crop. They are mulched from the hedge and the (**C**) pit. Some food scraps, ashes, mulch and shredded paper or plant waste are dug in to them in little pits, as are their own crop wastes and the cuttings from the windbreak plants (**W**). They are always in action, full of plants. Water is bucketed or reticulated from a mains system. Shower or bath–water can also be used, if run along a length of low–pressure leaky pipe.

J is a Fukuoka–style grain plot, mostly for people and partly for poultry. It has a low surround of dry–tolerant mulch such as *Centrosema*, but is also mulched from the hedge **E** and the palm clump **K**.

K is a circle or clump of 6–12 palms, of 1–4 species depending on site, tastes, availability, and needs. They ideally would be 2–3 coconuts, 2 oil palms, 2 dates, and a sugar palm, but may be simpler. The inside circle is mulched with their chopped fronds, their husks and wastes, ashes, and green hedge material or mulch brought in from other sources. In this deep mulch, a yam or vine will grow in the wet season.

Every dense black spot is a tree trunk; these are carefully–selected trees, and their crown spread is indicated. They can overshade the house roof, and may even be placed inside the house trellis, with holes in the roof to allow the trunk out. These few trellis trees have light crown and/or fruits that fall or that can be brought down by a child off the roof. They are intended to shade the roof area and can be tough, spreading legumes (*Prosopis* is good) yielding a food crop for livestock, or they can be palms, or a thin foliaged tree.

Other trees are producing staple fruits, a few avocado (on mounds 1 m high and 5 m across in wet areas), citrus, a few nut trees, and an oil palm. They have soft ground–cover below (nasturtium, soft legumes, comfrey) and this is sometimes slashed as mulch for the tree, sometimes fed to livestock.

The little hatched areas are the roofs of rabbit hutches and chicken roosts or pigeon lofts, quail houses, or guinea–pig rest areas (depending on the culture and preferences). A lot of the hedge (**E**), the wet mulch (**C**), the tree herb layer, and the spare corners are devoted to plants chosen just for the animals. Each little roof catches some water and leads it to a small tank or the garden or both.

Y–Y2) These are two fenced areas. They are changed over to suit the animals, and while one is rested, it can be cropped if space allows. Both are well–shaded animal runs. The fence can be of woven bamboo, palm rib, banna grass stalks, or of wire netting. Both areas are limed if sour.

The house trellis areas are very carefully fitted up with vine crop, spaced to let *some* light through (30% is fine). Basic vines such as chayote, kiwifruit, beans, cucurbits, and grapes are carefully chosen for the house trellis, which can extend 1–1.5 m above the whole roof area if the roof is sound and solid. One or two non–bearing vines can, in fact, be let rampage over the roof with great benefit to the cooling of the house. Note, however, the type of gutters needed in this case to catch the roof run off (**Figures 7.21** and **7.22**).

On the sides of this trellis, more ephemeral bean and cucurbit crop can be grown on leaning trellis of bamboo, or separate bamboo trellis can divide the G beds. There is no vertical limit to some vine crop, and if water permits, every palm in the K clump can eventually carry a high vine (granadilla, grape, or kiwifruit), as can any large leguminous tree (grape; kiwifruit is too dense). *Under* the trellis a few shade–tolerant plants will grow (coffee, taro).

or platform of wood over the mulch, and this then becomes an outside shower or wash–up area.

2. A circular sunken path 0.6–1 m (2–3 feet) wide is covered with sawdust or gravel around this central circle garden, and off it, 5–6 "keyholes" or indentations are made. The system now looks like **Figure 10.26.2**.

3. Around each keyhole a bed 1.5–2 m (5–6 feet) wide is first edge–banked with soil 100–200 cm (4–8 inches) high to prevent water run–off, and the beds are then papered and mulched (as for the banana circle). The whole garden now looks like **Figure 10.26.3** in plan. The thick lines represent low earth ridges.

Thus, we have six major keyhole beds, each of which is separated from the next by a thin strip of lemongrass *(Cymbopogon citratus)* or Vetiver grass *(Vetiveria zizanioides)*. Just outside the periphery ridge, strips of lemongrass, comfrey, and arrowroot *(Canna edulis)* form a kikuyu grass barrier, and behind that, a taller border of cassava/banana/papaya/pigeon pea/*Leucaena*/ *Crotolaria* forms a hedge or windbreak. All these borders give mulch, forage, barrier effects, or food. The whole mandala is fenced or has a spiny woven hedge boundary for cattle exclusion, if necessary.

The mandala has now been earth–shaped and mulched to prevent water run–off and to conserve moisture. We now proceed to plant, using buckets of good soil to place the following zones of plants:

A. On the track edge border of the central path and keyholes, within stoop–reach of the path, plant those frequently–plucked or everyday greens of high value. Here, the placement and selection criterion is that *all the plant, or most of it, is picked for much of the year*. These are the PATHSIDE GREENS; they include all the chive and shallot species, plenty of parsley, coriander, thyme and sage, celery, broccoli, edible chrysanthemum, chard, and any such long–bearing or perennial greens (e.g. various perennial spinaches). This is therefore a narrow border to the inner side of the keyhole beds, planted in the ridge soils there.

B. Behind or outside the pathside plants, we plant a 1 m (3 foot) wide strip of species which are *frequently picked over a short to long season*, e.g. tomatoes, eggplants, bell peppers and chilies, bush or staked beans and peas, kale, corn, okra, and so on. These are the NARROW BED plants, all within reach of a path or keyhole. As yet, we do not need to step on any beds to harvest.

C. Just out of reach, on the outer borders of the keyhole beds, we place most long–term root crop (potatoes, sweet potatoes, carrots) or any crop we CUT AND REMOVE (cauliflower, head lettuce, and cabbage). Thus, for this crop we step (once) on the bed to harvest and replant, following root crop with fava beans or dahl (dried beans or lentils).

All beds are replanted as they are harvested, and a top mulch of straw, sawdust, bark, dry manure, or chips is added annually. Rabbits, guinea–pig, chickens, or small livestock are fed from weeds, waste vegetables, household scraps, and forage greens from the border hedge (comfrey, cassava, *Leucaena* or lemongrass). Vetiver grass, lemongrass etc. are cut 3–5 times annually for mulch. The roots of Vetiver grass prevent rodent burrowing from outside the system, as do the root masses of *Euphorbia* species.

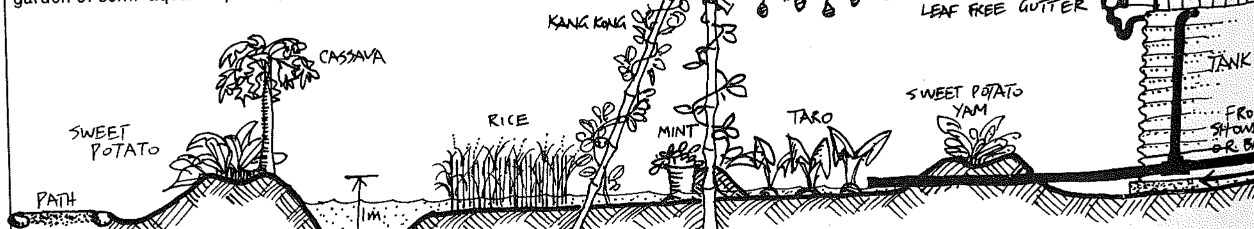
All trees, shrubs, and tubers are planted before papering and mulching, then about 30 cm (1 foot) of trodden–down and wetted mulch is added. Tray seedlings 8–10 cm (3–4 inches) high, and large seeds such as peas or beans, are each planted in a hole burrowed in this mulch, with a good double handful of soil to each hole. Small seeds (lettuce, carrot) are scattered thickly on lenses of soil 50 cm (1.5 feet) across and 5–8 cm (2–3 inches) thick, placed and firmed on top of the trodden mulch, followed by dusting of a 1 cm (1/2 inch) thick layer of fine soil. All seed can be pre–soaked. The whole bed needs a good soak with a sprinkler at each stage.

If no weed seeds are included in the mulch, the beds are weed–free. It takes 9–15 months to build up worms and a good soil. Any surplus compostables can be pushed under the top mulch layer.

A larger system, designed for a community kitchen at a rural centre in Karnataka state (India), uses a core assembly of 4–5 banana circles, and has 8–12 keyhole beds. In this case, a keyhole accesses the banana circles **(Figure 10.26.4)**.

Any one of these banana circles can contain a small

FIGURE 10.24
DETAIL: Wet food patch.
Roof and tank overflow plus greywater can irrigate a "wetland" mulch garden of semi–aquatic species; banks accept dryland species.



pond for frogs and water convolvulus, or taro. We can plant a *Leucaena* or palms for high shade and mulch, at the junctions of the keyhole beds. The hedge surround eventually provides the annual mulch (**Figure 10.26.5**).

This garden is intensively–planted, has very little path per bed area, is easy to build and maintain, provides everyday greens, minerals, vitamins, allows no water run–off, and can be built on *any* substrate (rock, concrete, roof areas).

We can here combined basic nutrition, soil building, rainwater harvest, eventual self–mulching, various weed and animal barriers, small livestock fodder, overhead shade, non–dig gardening, "least–path" access, direct waste water disposal, and a pleasing design.

AVENUE CROPPING

The system described here is adapted from Ray Wijewardene, 1981, *Conservation Farming*, IITA–Sri Lanka Program, Dharmapala Mawatha, Columbo 7, Sri Lanka. It is a deliberate fuelwood/mulch/soil improvement crop integration of great use in the tropics but adaptable to any climate, with good species selection (**Figure 10.27**).

The essentials are simple enough:

- Correct spacing to shade the ground fully but to allow cropping between the tree legumes.
- Lopping to leave stems 0.5–1.0 m above ground (a suitable tree legume is tagasaste or *Leucaena*).
- Sowing of crop just before rain or irrigation, to beat the growth of weeds.
- Possible two–crop sequence, with mulch also returned from crop wastes.

A very similar system is used in Africa with *Gliricidia*, and more recently in New Zealand with tagasaste as the green crop. A parallel system (regular or irregular in ground plan) is successful in establishing small trees, which otherwise perish from frost or in open grass competition.

At least two problems arise in sustained coppicing of legume trees. Firstly, such coppice should be confined to warm wet periods, allowing mature leaf to carry over into dry, cool, or frosty periods. Secondly, constant coppice weakens trees over 5–8 years, and replanting is necessary. Very few legume trees will sustain constant coppicing, and other strategies are called for. Perennial thin–crowned leguminous trees can be spaced throughout the orchard and garden, or fast–growing and short–lived legumes can be allowed to grow and die, or can be ring–barked or felled on a 2–5 year cycle.

However, with permanent high legume cover, mulch can be obtained all year from a variety of non–legume hedge and understory. Such species as *Nicotiana*, *Echium fastuosum*, *Lantana*, cinnamon, even clumps of daisies, wild ginger, lemongrass, Vetiver grass, *Pennisetum*, and crop wastes from maize, *Sesbania*, and soft ground legumes or comfrey provide constant mulch under high legume cover, so that the coppicing of susceptible legumes themselves is reduced or eliminated.

In any evolved system, avenue cropping or mulch provision can be sustained by a carefully–planned system of mixed non–coppiced tall legumes giving a seasonal leaf drop (*Erythrina*, *Tipuana tipu*), and a row series of non–legumes for ground mulch.

BARRIER PLANTS

There are several reasons to erect barriers of plant species:

- As a block around the annual garden to resist invasive grasses (such as kikuyu and buffalo grass, knotweeds, etc).
- As a corral for animals, or to keep grazing animals out of a compound, or to guide animals to a gate or

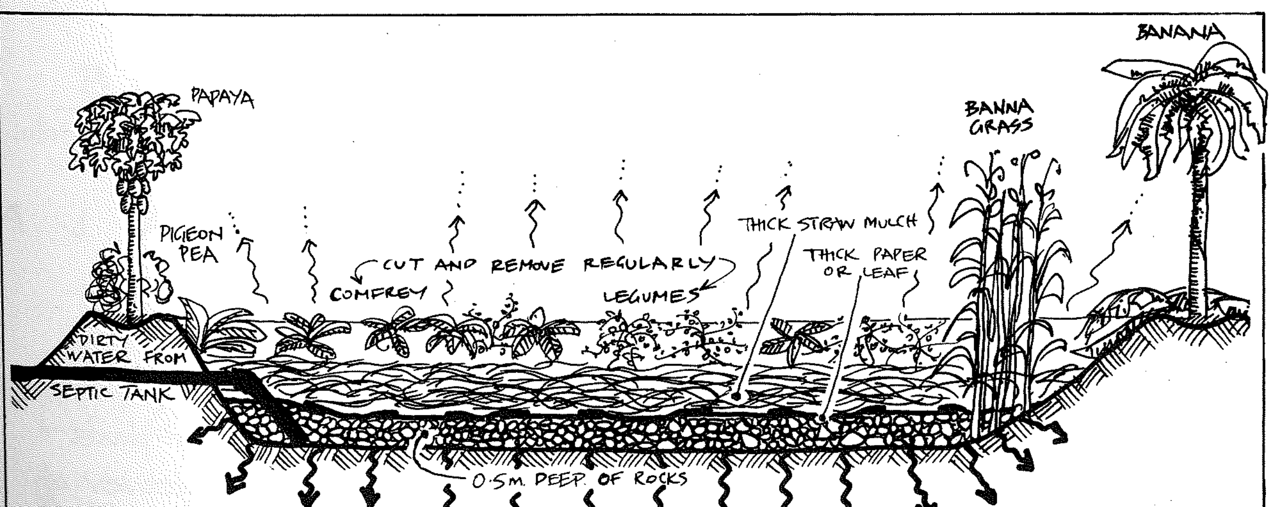


FIGURE 10.25
DETAIL: Dirty water patch.
Sewage fed to a mulched 5 x 8 m stone–pit allows a surround of useful species; mulch can be grown in the pit.

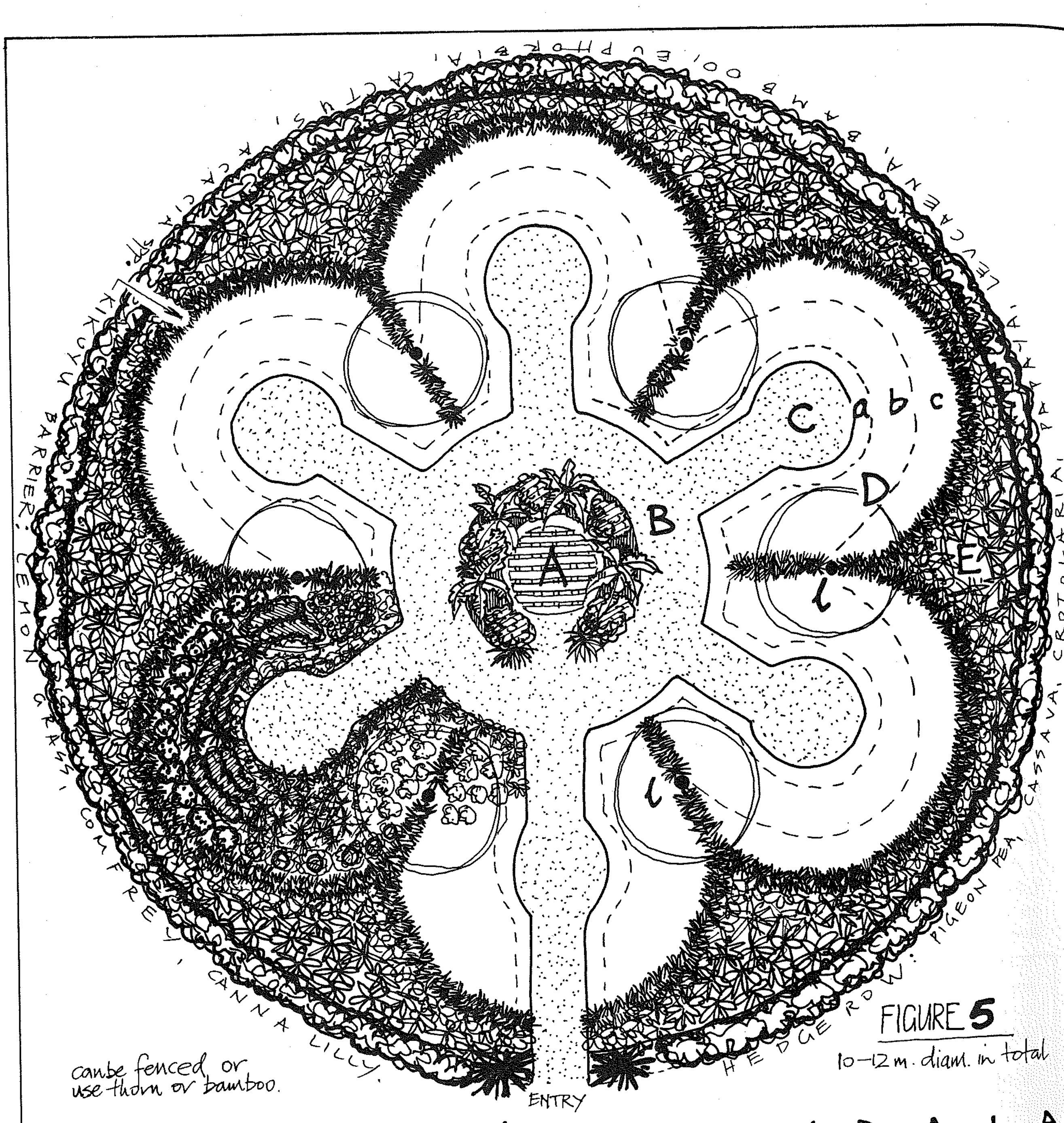


FIGURE 5
10–12 m. diam. in total

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A Banana– Papaya circle with shower-wash grid fitted.
B Sawdusted, rice husks, or gravel paths
C Keyhole paths as B above
D Keyhole beds **a** pathside plants **b** narrow bed plants **c** one visit plants
E Weed, wind, animal barrier hedge sequence, e.g.: (inner → outer) Vetiver or lemon grass, comfrey, arrowroot; taller hedge of cassava, papaya, crotalaria, leucaena, pigeon pea, and banana.
l In garden trees are leucaena or palms for shade in hot regions.

FIGURE 10.26
GANGAMMA'S MANDALA.
An ideal "least path", zero–runoff, acessible layout for tropical home gardens. FIGURE 10.26.4 shows how this mandala can be scaled up for group gardens at schools, villages, etc. Gangamma is an Indian permaculture student.

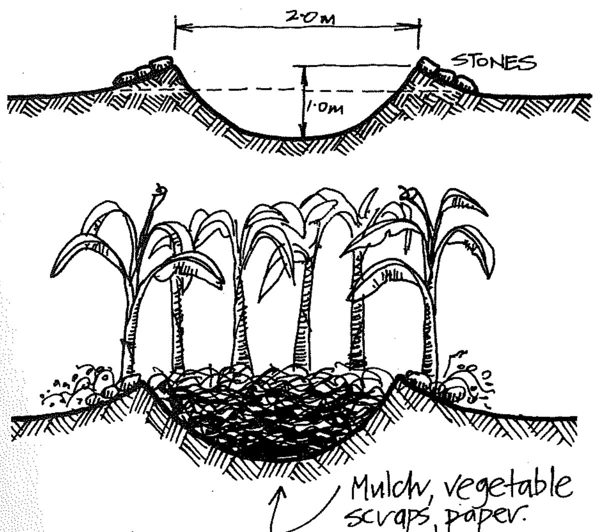


FIGURE 1
Sectional elevation of banana/papaya circle.

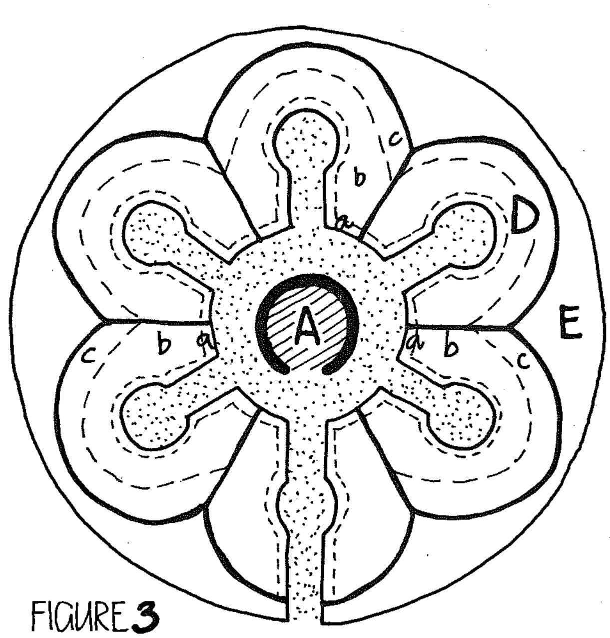


FIGURE 3
D Keyhole beds about 1·5m across.
E Hedgerow & barrier plants.
ZONES IN KEYHOLE BEDS:
a Pathside greens.
b Narrow bed plants.
c One visit crops.

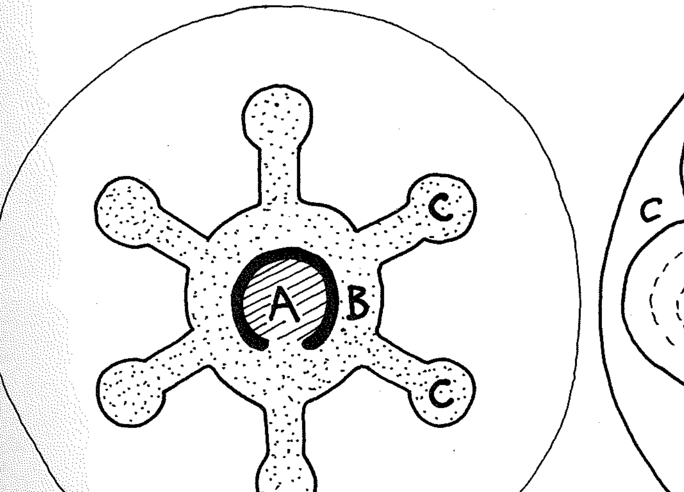


FIGURE 2
A Mulch or circle garden = "banana circle".
B The annular path.
C The keyhole paths.

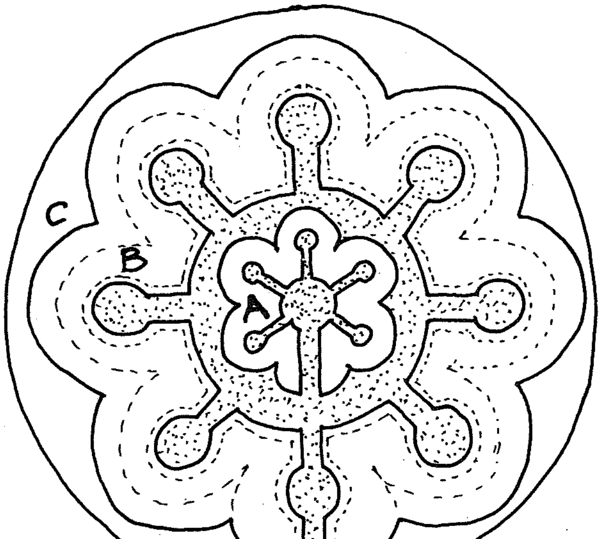


FIGURE 4
A 5 "Banana circles"
B 8 Keyhole beds
C Hedge and barrier.

corral.

• Against hot, dry, or salt–bearing winds, on seacoasts, cliffs, or exposed sites.

• As contoured strips to disperse overland water flow, to catch silt, and to prevent erosion of soils.

Garden Barriers

Around annual, mulched gardens laboriously freed of weeds, a band of grass–barrier plants prevents weed re–invasion. There are 4–5 forms of plants which are effective, and all of them can be used if space permits:

• A deep–rooted broadleaf (e.g. comfrey).

• A clump grass which does not seed down or is not browsed (e.g. lemongrass, Vetiver grass).

• A carpeting plant such as sweet potato, nasturtium, or *Impatiens*.

• A dense low shrub (*Oncoba, Corposma, Echium*).

• A bulb such as *Canna, Agapanthus*.

In total, the same plants can form a fire barrier, provide ample mulch for the garden, and if initially cared for, establish in one season. When first placed, they need to be mulched, manured, and watered.

Animal Barriers

Corrals or cattle–goat–sheep barriers can be strengthened with one or two strands of barbed wire, but should have the potential to resist on their own. Thus, they involve thorny or distasteful shrubs. These can either be planted as a hedge, or as a coppice crop which is cut and built into a thorn fence (boma). The latter enables more flexibility in changing the arrangement of compounds, while the former is less trouble.

Species ideal for such bomas are *Lycium ferocissimum, Acacia tortilis, Oncoba spinosa,* and *Euphorbia tirucalli*. Of these, only *Lycium* and *Oncoba* may not need

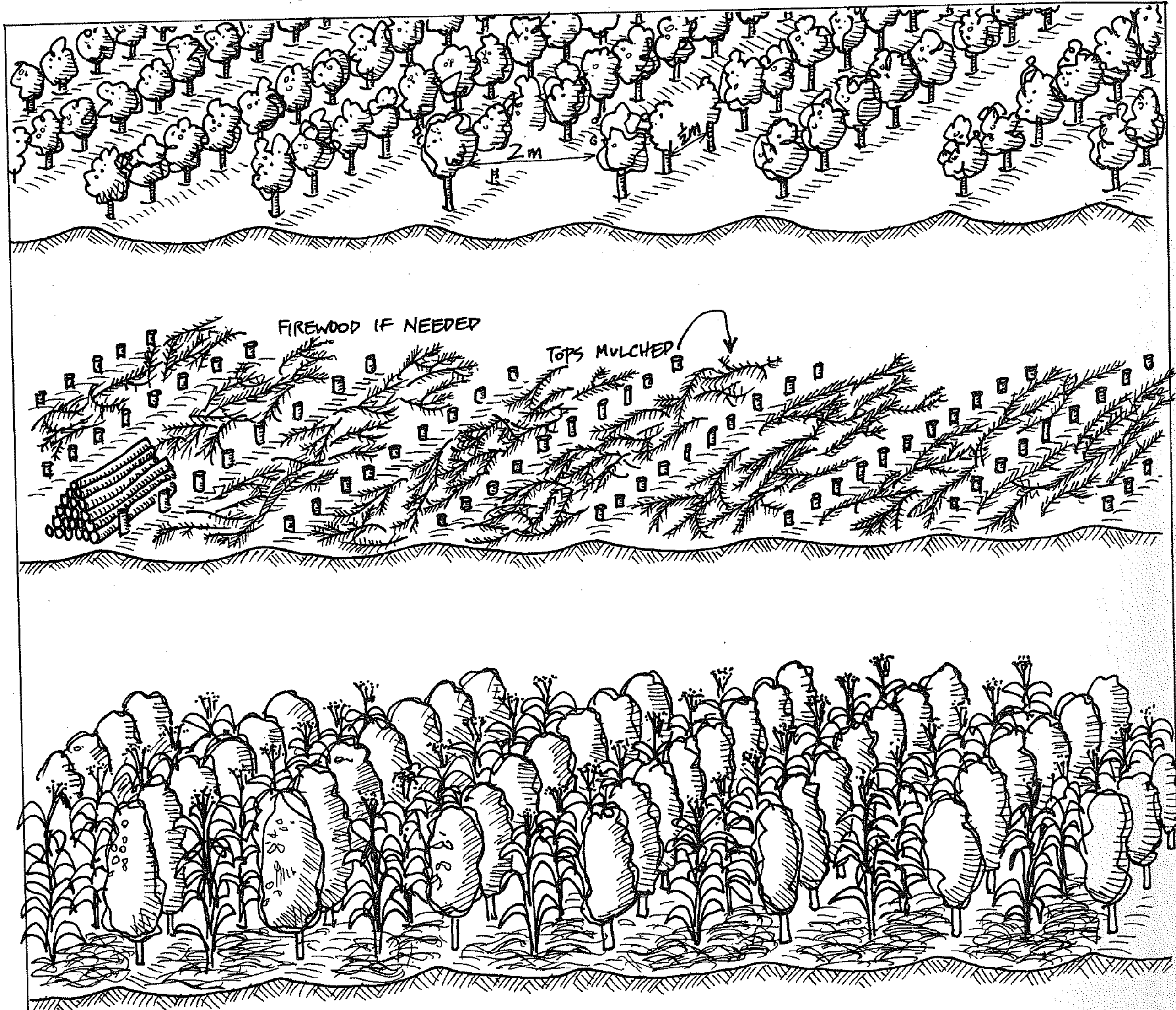


FIGURE 10.27
AVENUE CROPPING.
Coppicing legumes (*Leucaena, Cassia, Acacia, Glyricidia*, etc) cut annually provide nitrogen and mulch for intercrop such as maize, sweet potato. ginger, pineapple; crop wastes are returned to field; firewood is a by–product.

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

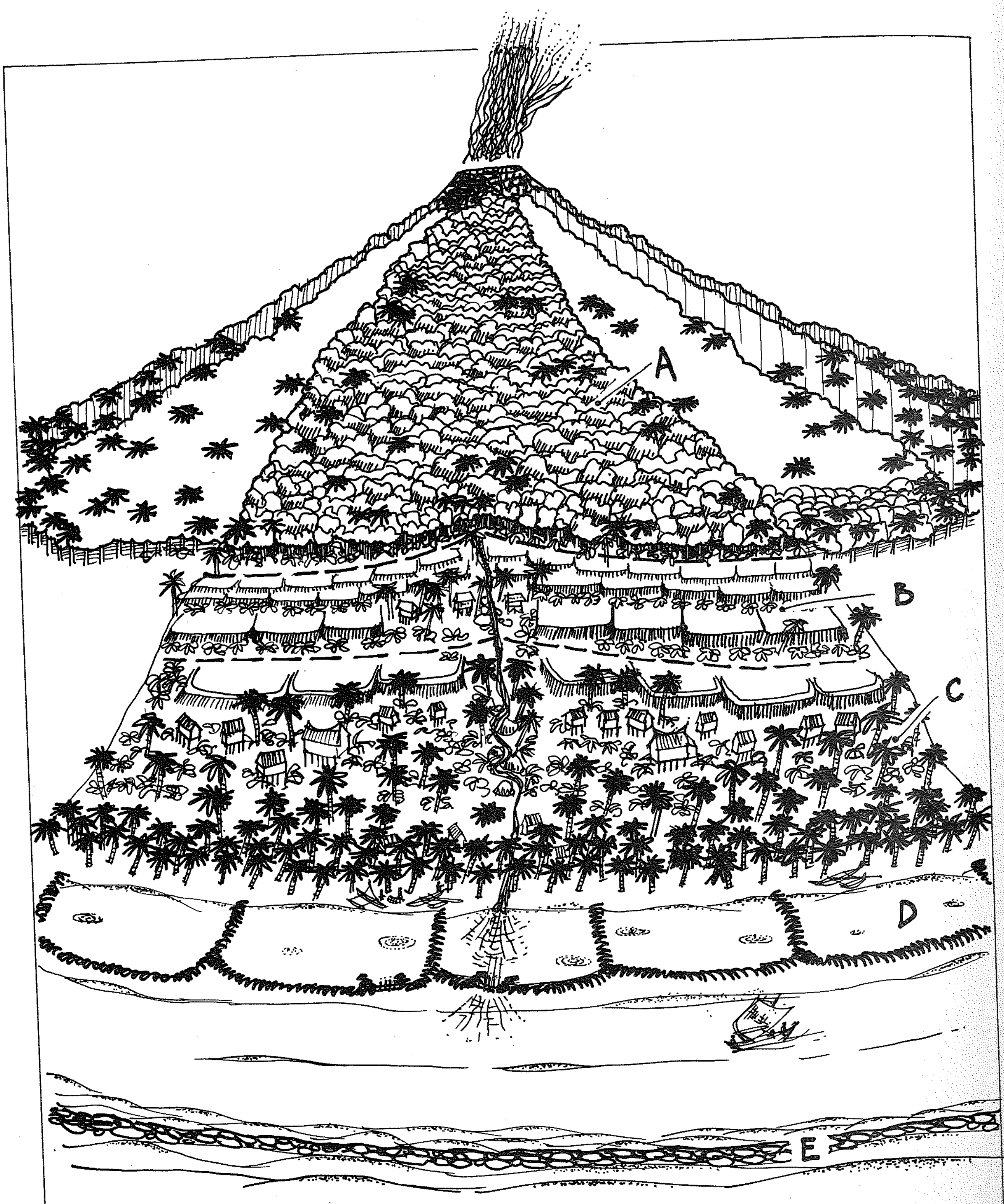


FIGURE 10.28
OHANA SYSTEM (Hawaii).
One radial valley of a volcanic island. A - "taboo" forest of upper slopes; B - stream diversion to ridge or high terraces, main village; C - sacrificial forests of palm to modify hurricanes; D - reef fish ponds to retain leached nutrients, growing mullet and shellfish;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

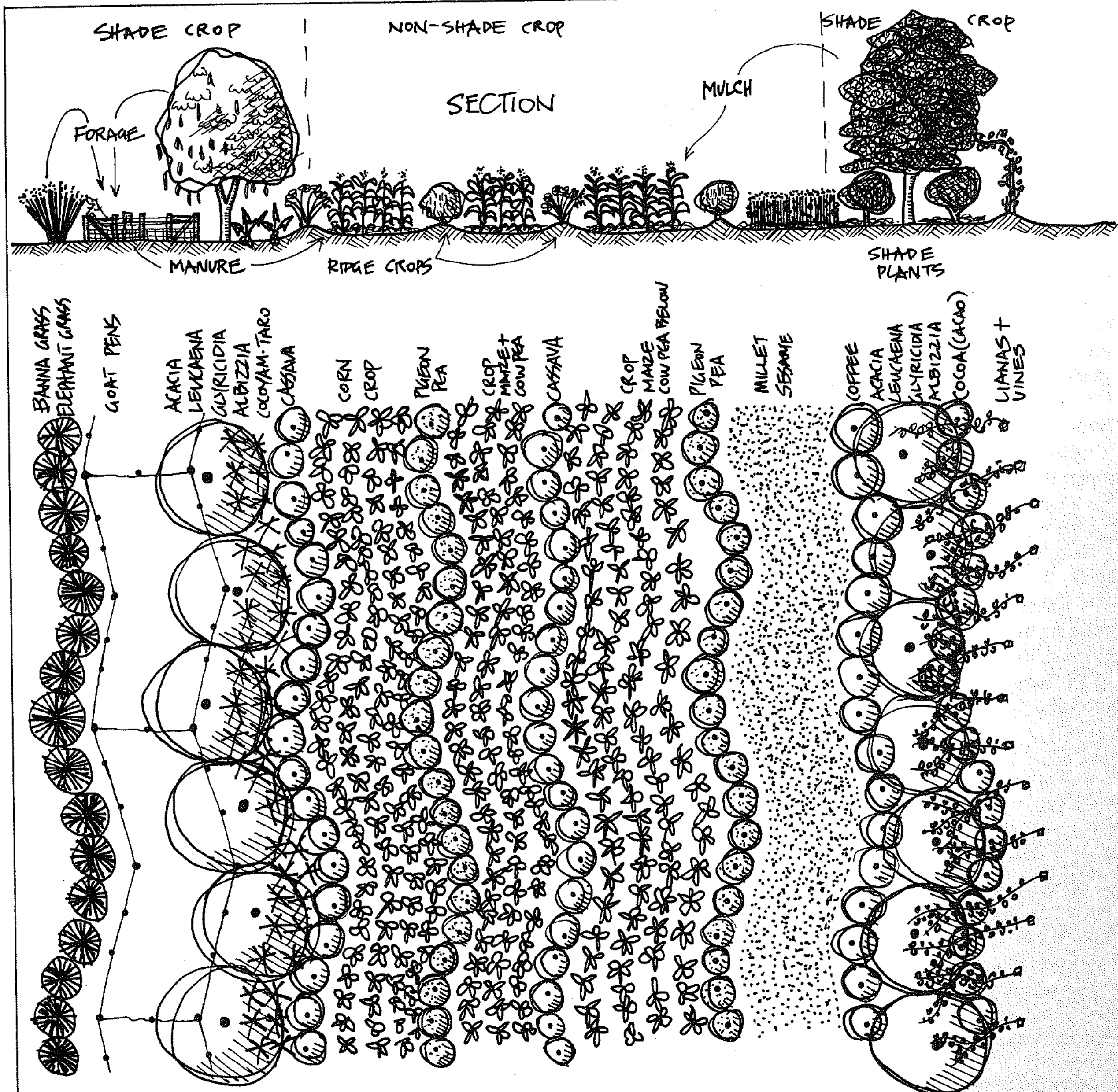


FIGURE 10.29
NIGERIAN POLYCULTURE FOR HUMID TROPICS.
Includes pig or goat pen and forage crops appropriate ridges for cassava, strip crop, zero runoff; contour layout. [Data from Gkiebo and Lal].

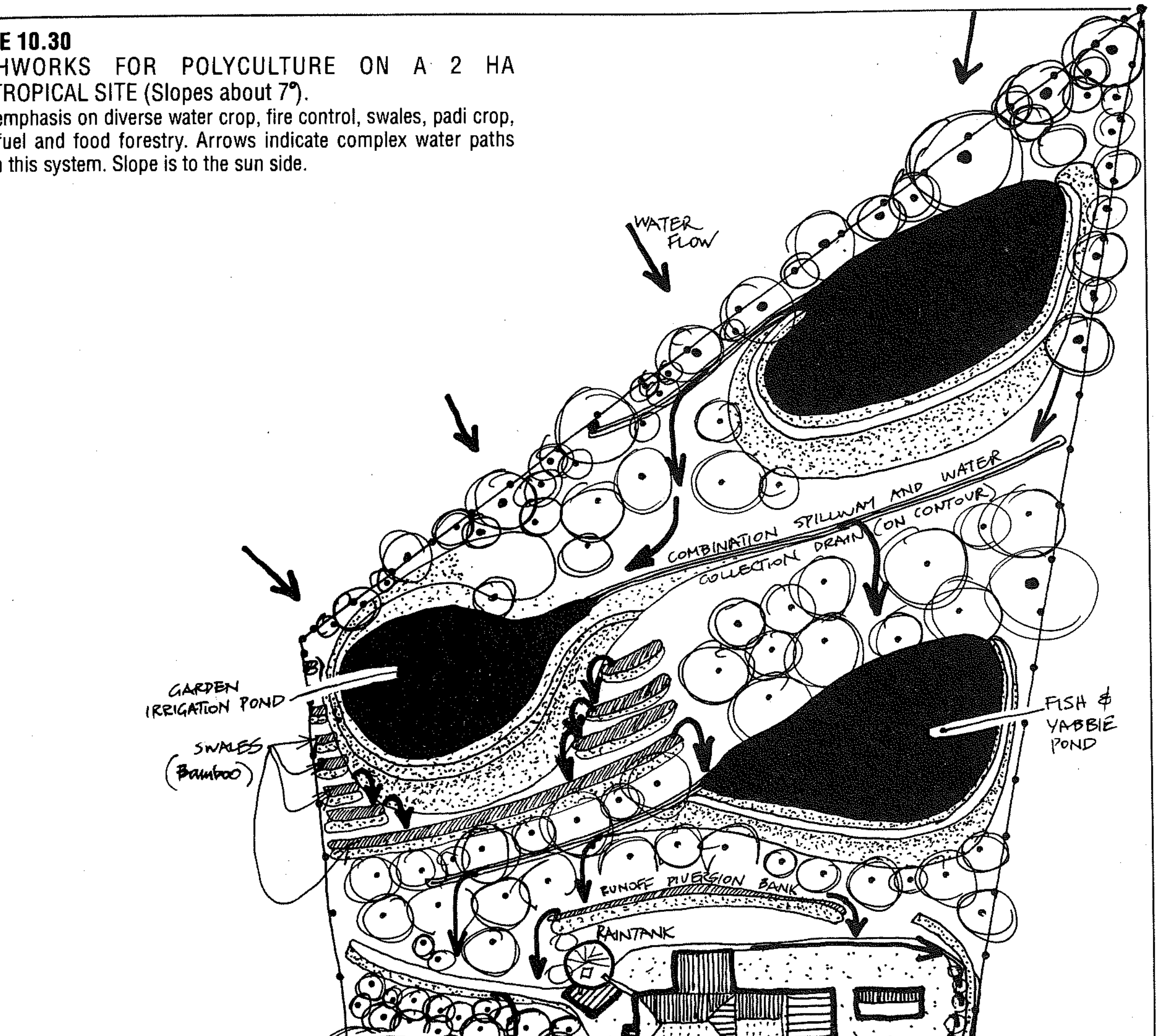


FIGURE 10.30

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:

In village: 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.

In palms, 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).

Considerations for Varietal Selection

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 varietes.

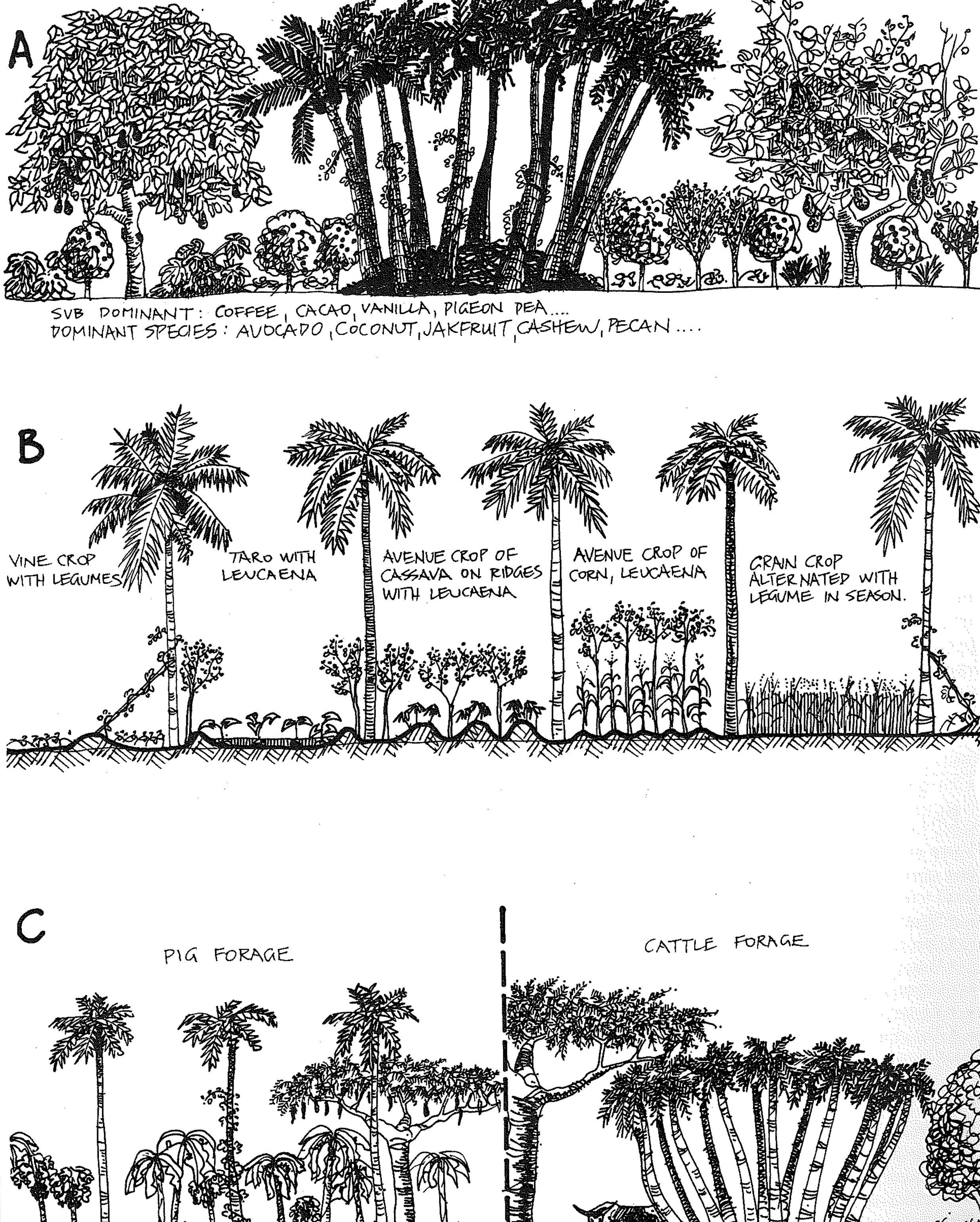
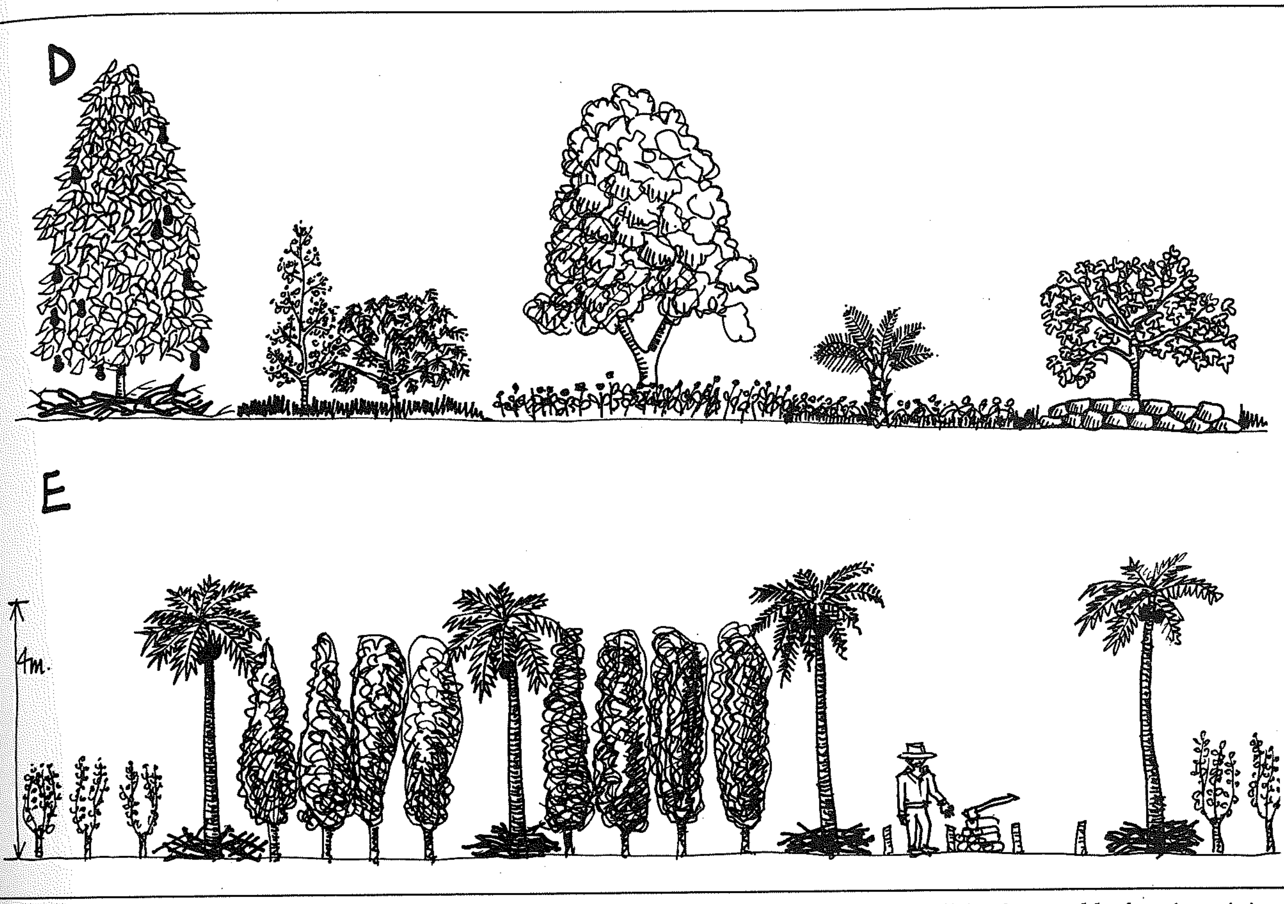


FIGURE 10.31
A–E STRUCTURAL VARIATION IN PALM POLYCULTURE.
A - Palms–fruit layout; B - Palm row crop; C - Palm–pig forage or cattle forage; D - grassland evolution; E - Fuelwood plus palms. All can be zoned around a village.



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 characteristics, 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

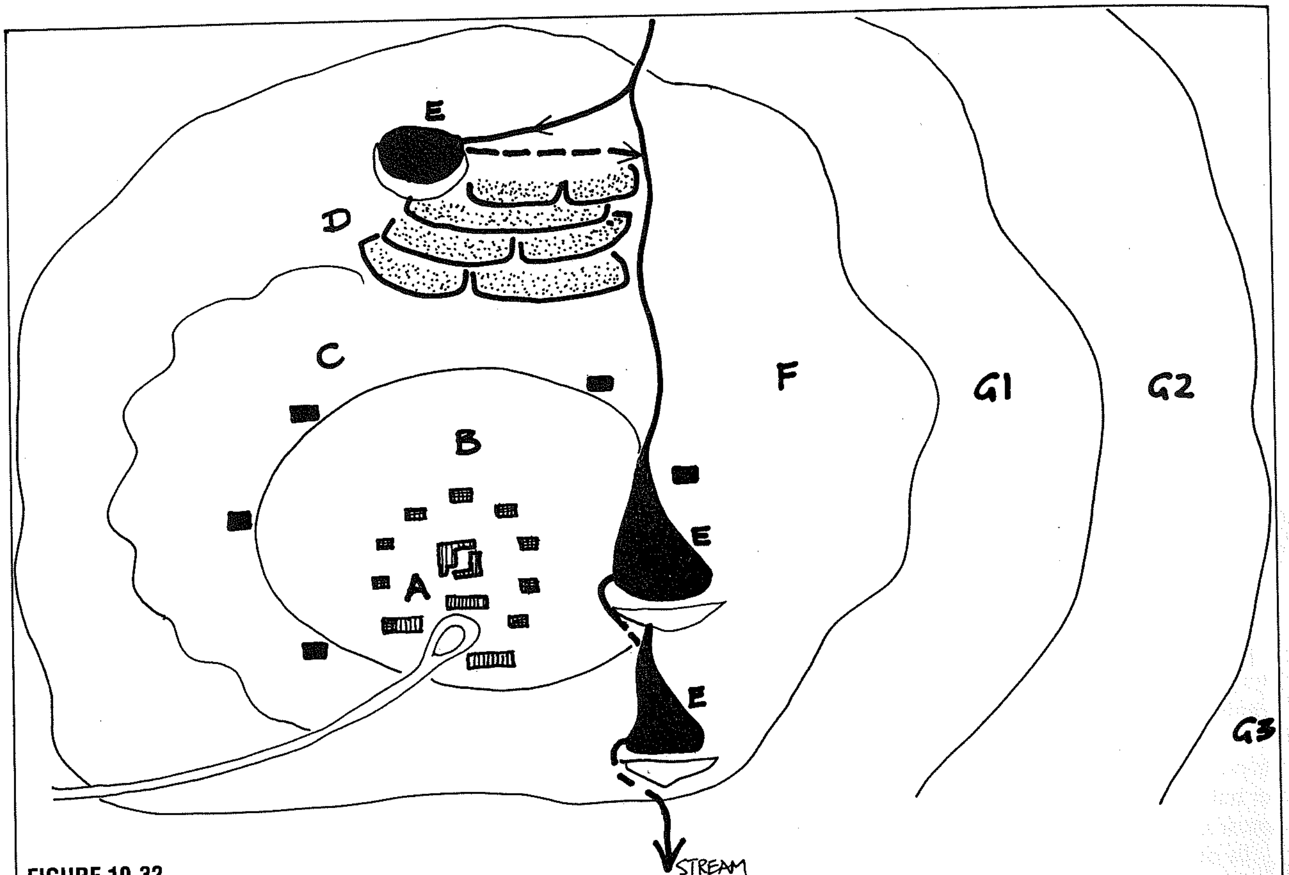
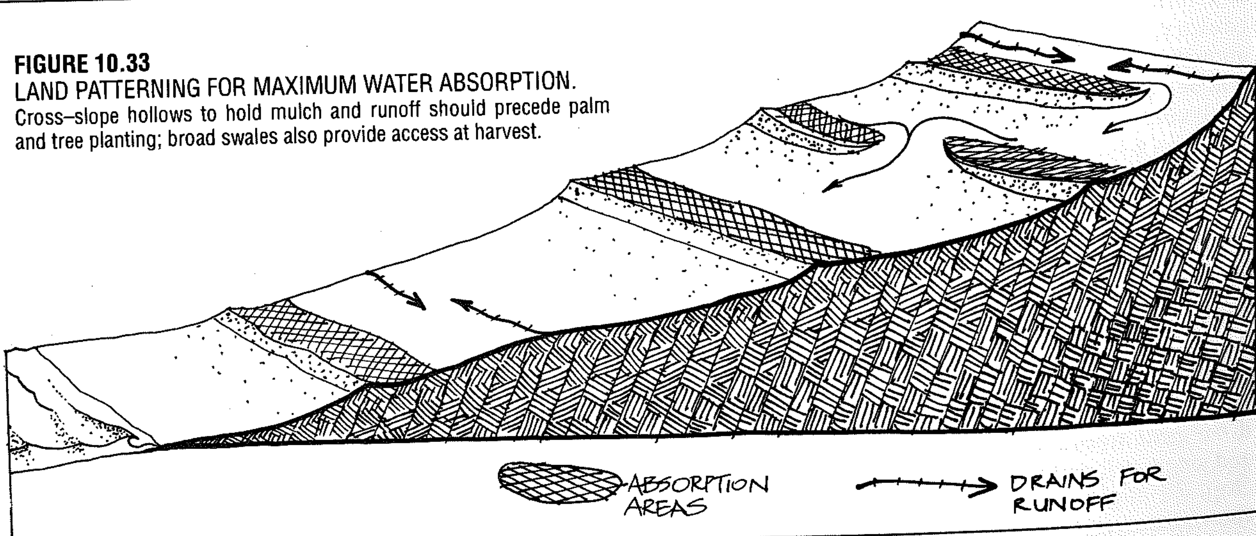


FIGURE 10.32
APPROPRIATE VILLAGE ZONATION.
A - livestock; B - Palm polyculture; C - Forage for larger animals; D - Padi crop; E - Header dam and aquacultures; F - Commercial crops in palm; G1–G3 - Reduction in species and increase in wild gathering - fuelwoods and hardy trees.

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

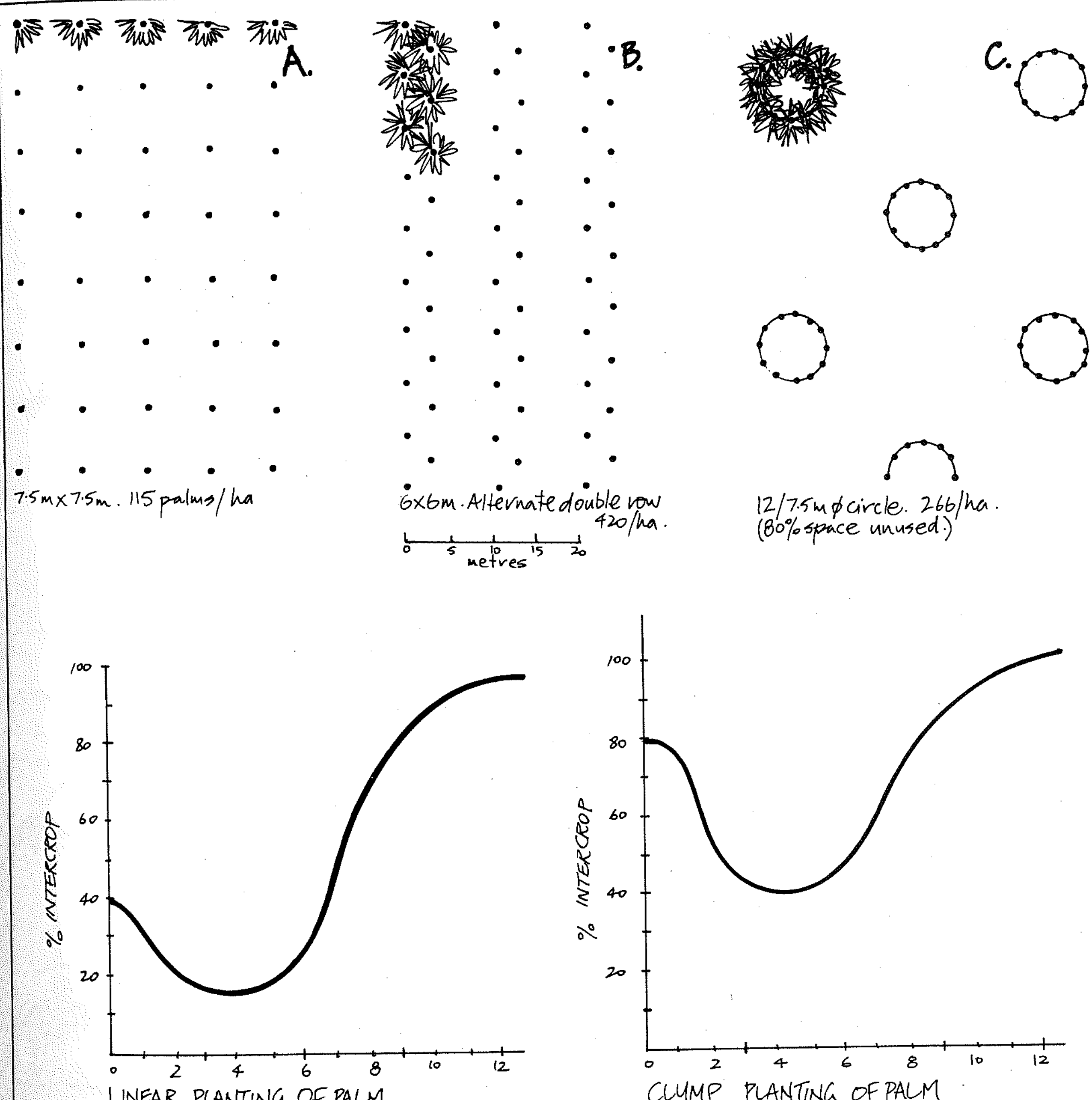


FIGURE 10.34

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

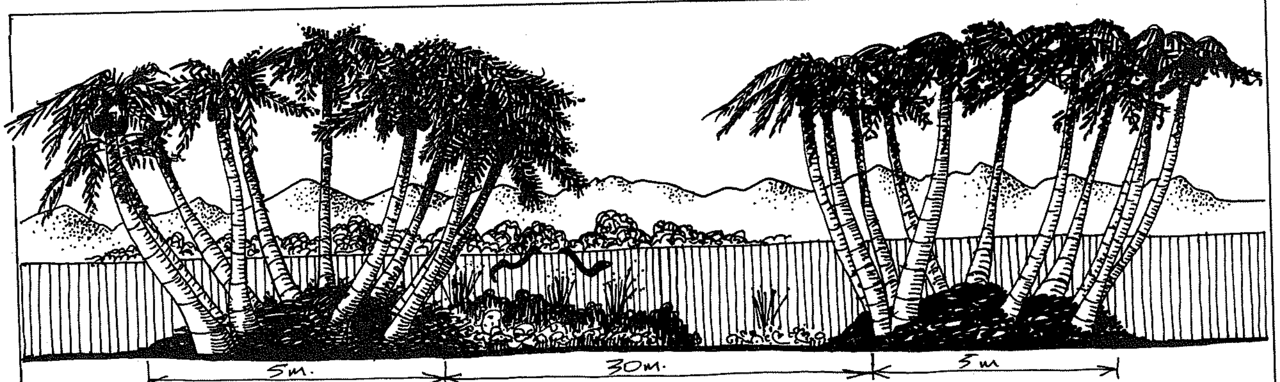


FIGURE 10.35
PALMS PLANTED IN CLUMPS.
Palms, bananas, macadamia nuts and many other useful species yield well in clump plantings, freeing space for intercrop and concentrating mulch and irrigation needs.

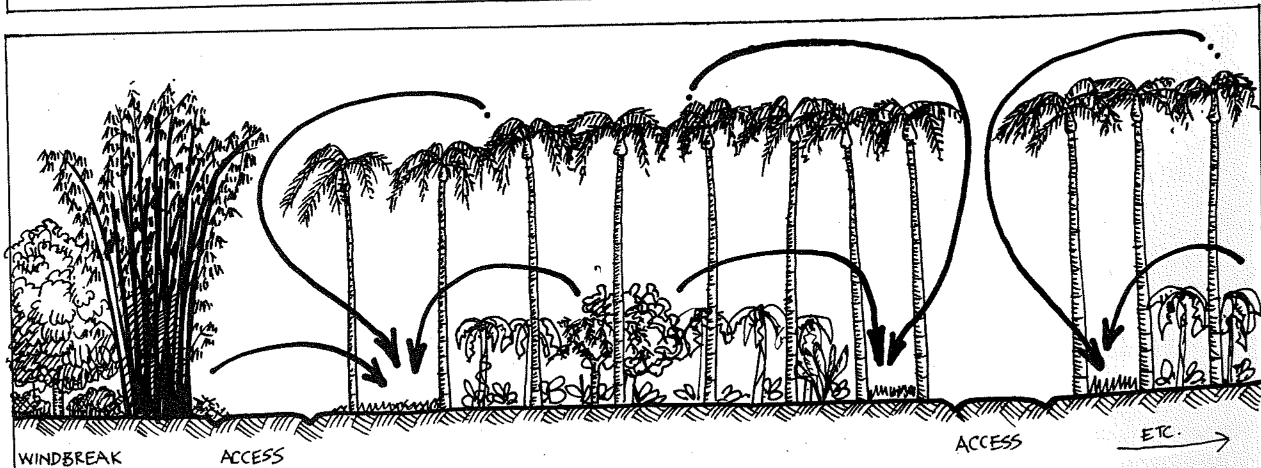


FIGURE 10.36
LAYOUT OF PLANTATION FOR MULCH.
Palm fronds, nut husks, hedge foliage, and intercrop leaf all suffice to heavily mulch every 4-5th strip each year for high yield annual crop.

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-

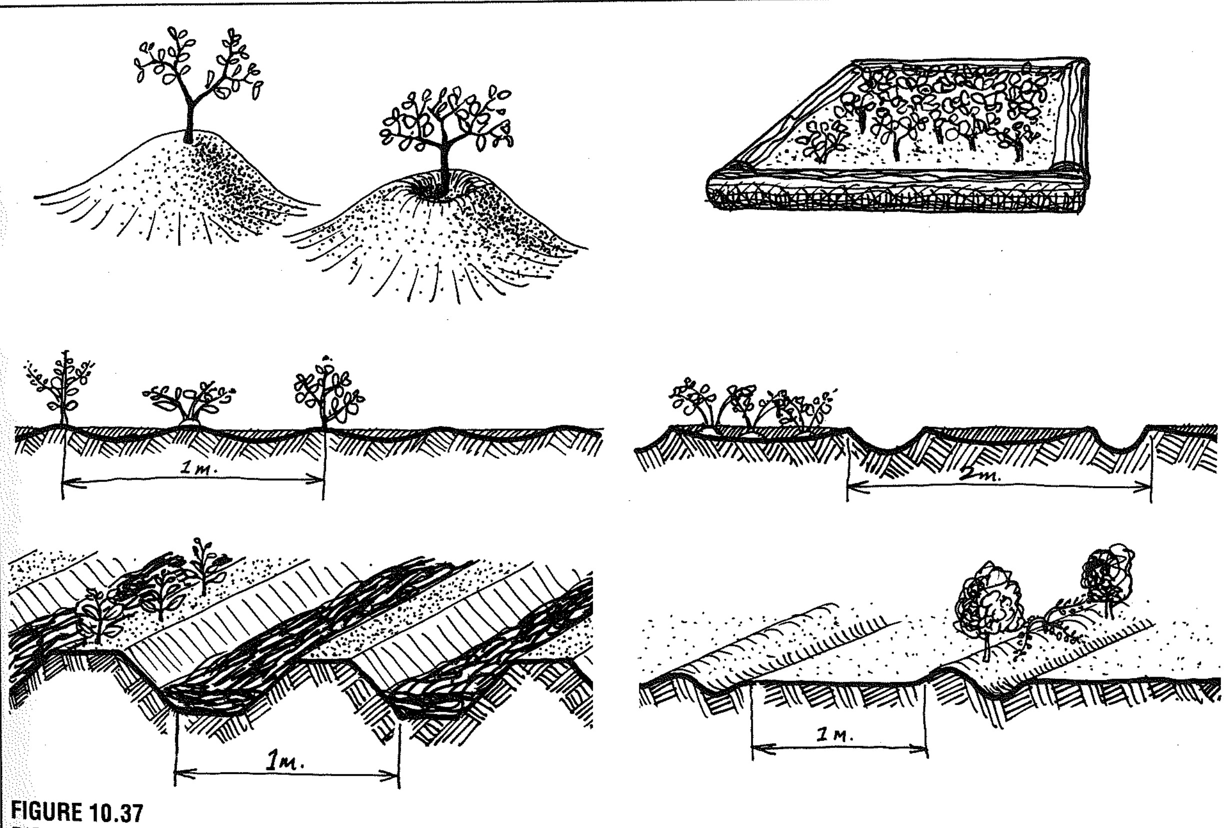


FIGURE 10.37
RIDGES, MOUNDS, FURROWS, BOXES.
Appropriate earth–shaping specific to crop type or soil (drainage) precedes all planting operations and increases yields.

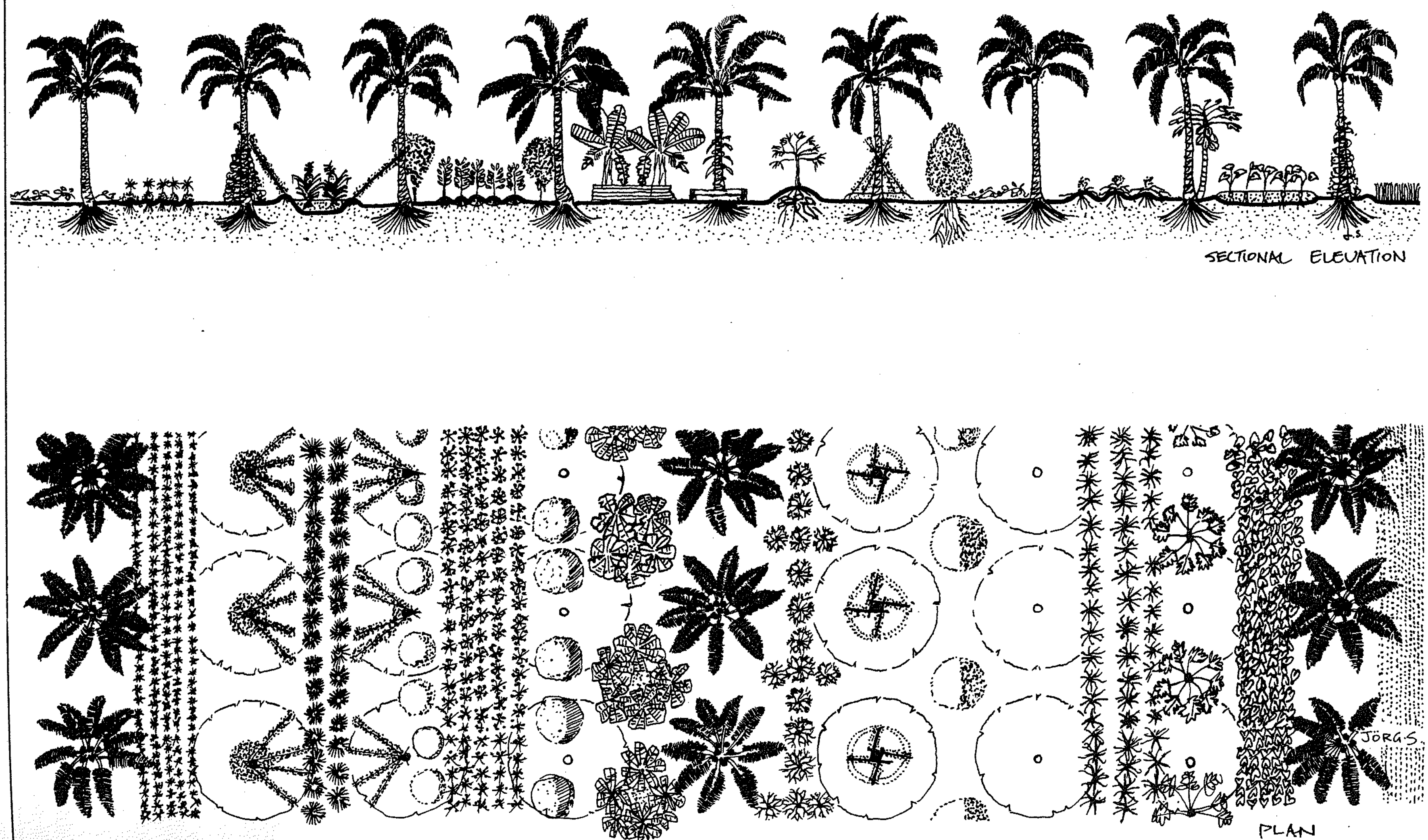


FIGURE 10.38
PALM INTERCROP .
A wide variety of crop, and accessory earth, or trellis, structures can be integrated with palms after years 4–7. [Jörg Schultz].

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

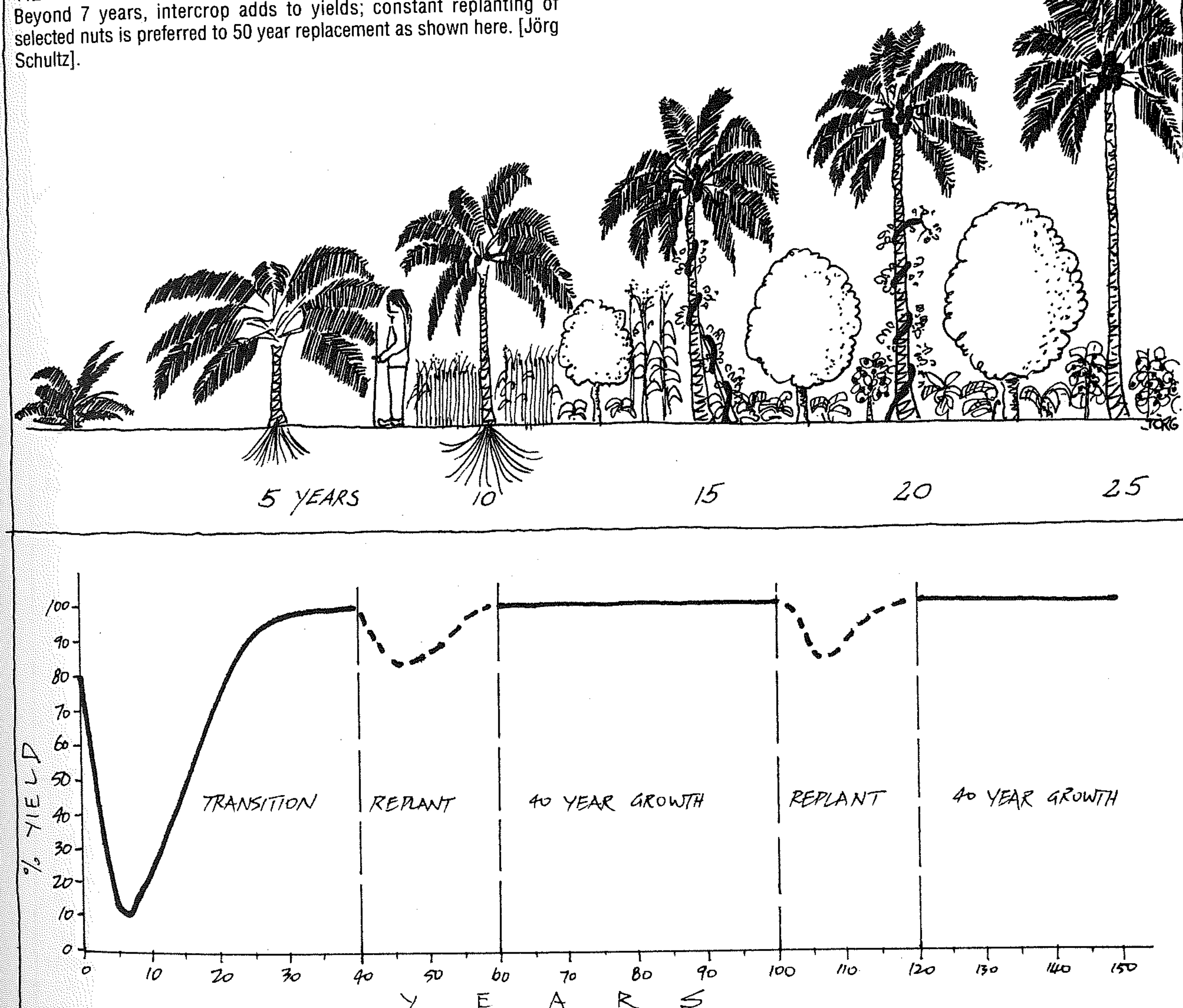
Nair (1975) gives convincing economic analyses for coconut, showing a 50% increase in yield for irrigation alone and a trebling of the yield for complex intercrop of two or more species, effectively doubling the cash return to the grower on the same area. Costs of irrigation and intercrop (plant or animal) 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.

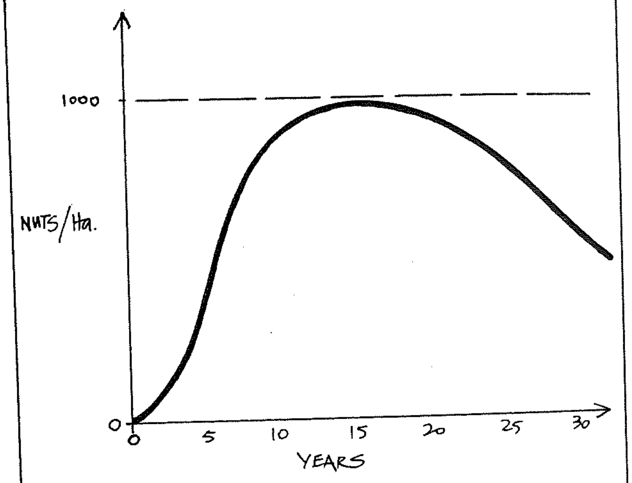


FIGURE 10.40
SCHEMATIC OF A PALM POLYCULTURE.
Nut yields; slow decline after year 15 requires that selected planting of 1/20th of area is a continuous management process which yields logs, mulch, and variable age across stand.

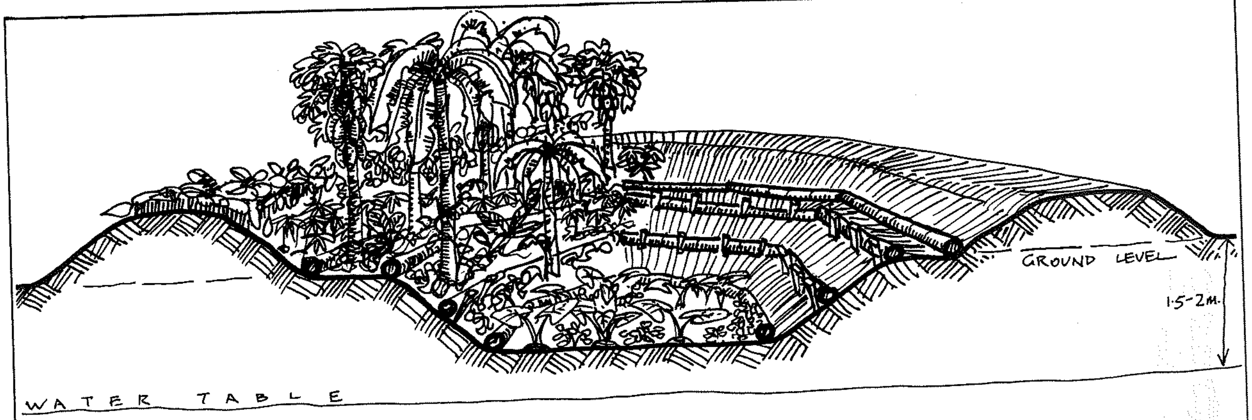


FIGURE 10.41
PLANTING BENCHES IN PITS ON CORAL ISLANDS.
Grow-pits 1–2 m deep and 8–12 m wide are ideal in coral sands; lower levels are close to permanent water table. Mulch reduces pH to 7–7.5.

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.

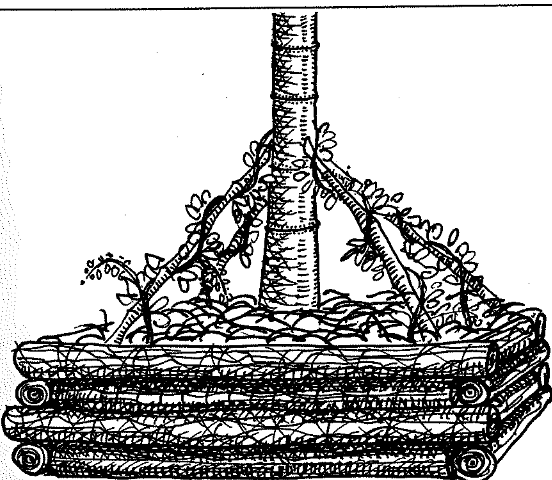


FIGURE 10.42
MULCH BOXES MADE OF PALM TRUNKS.
Palm– or log–surrounded areas filled with mulch are ideal for vanilla, yams, beans, cucurbits in sandy or alkaline soils; also on a larger scale for potato, tomato.

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

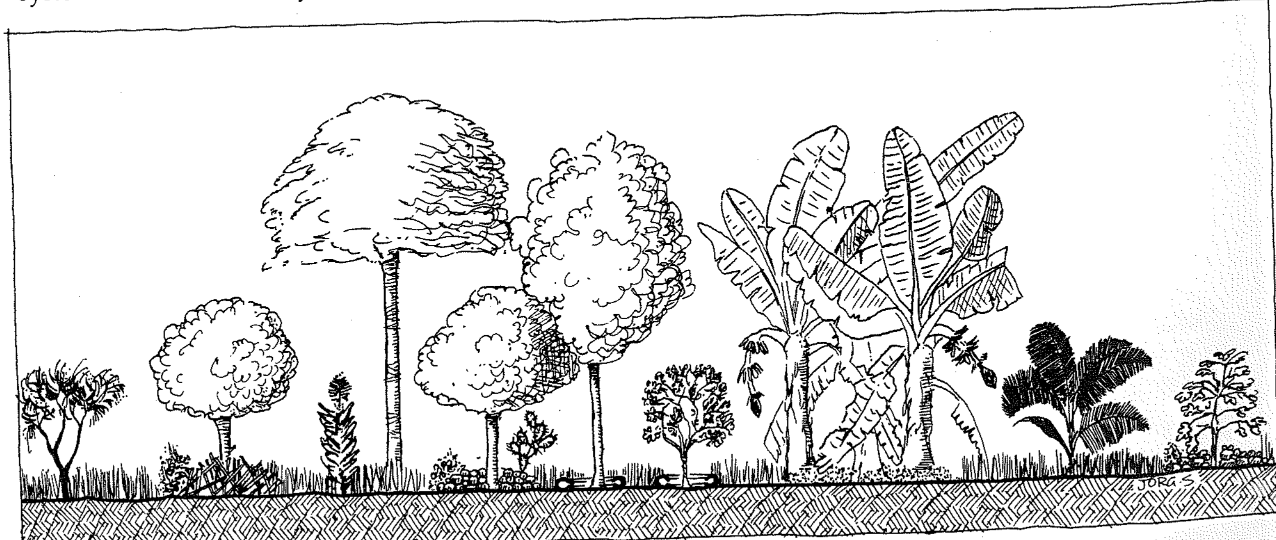


FIGURE 10.43
PLANTING IN GRASSLANDS.
A dense (2 x 2 m) planting on "nucleii" of legumes, palms, shrubs, ground covers, and bulbs plus stone or stick mulch quickly shades out grasses and produces a closed canopy. [Jörg Schultz].

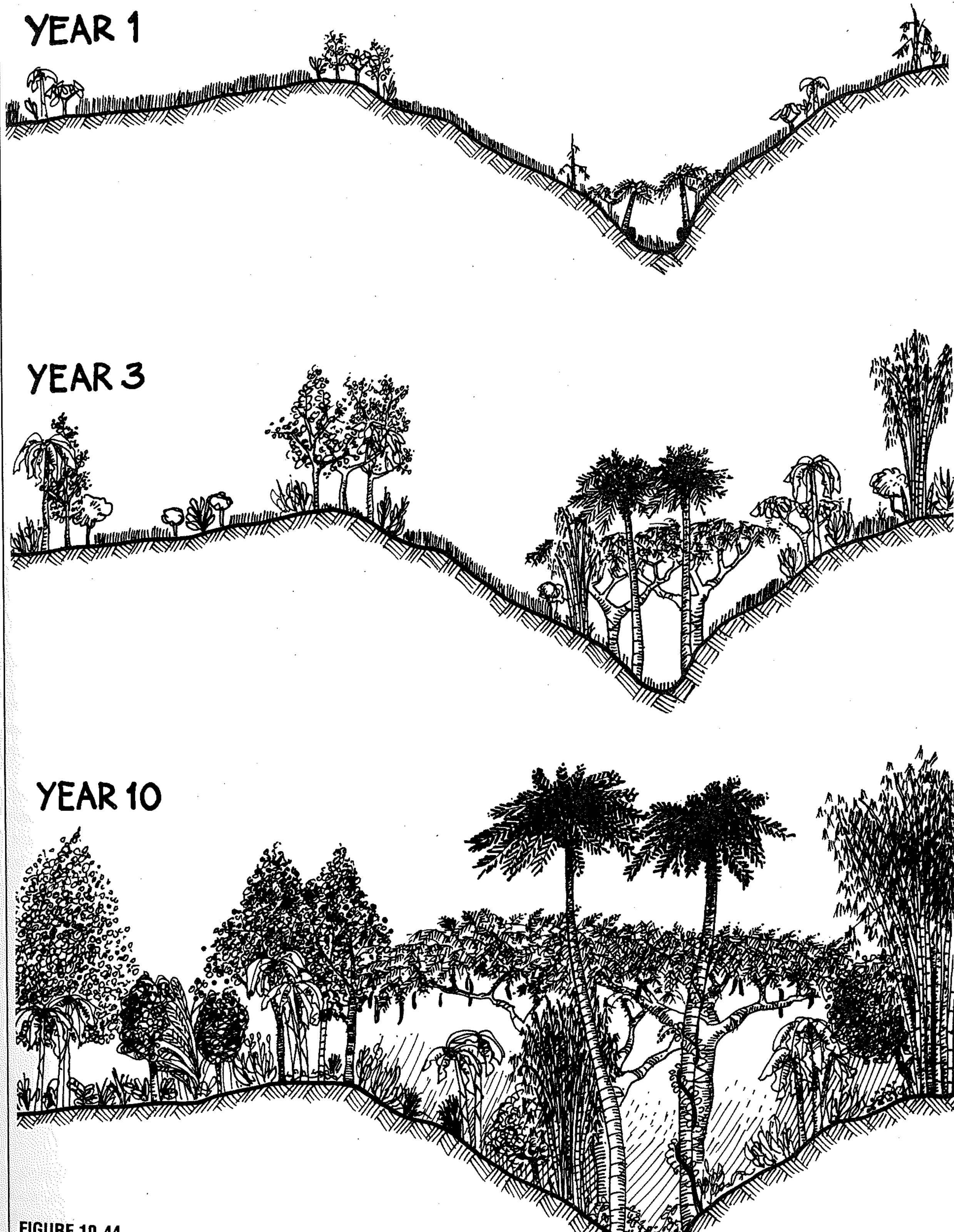


FIGURE 10.44
NUCLEUS PIONEER COPSE IN GRASSLANDS.
Dense nucleus mulched planting joins up to create self–generating forests in grasslands within 10 years.

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.

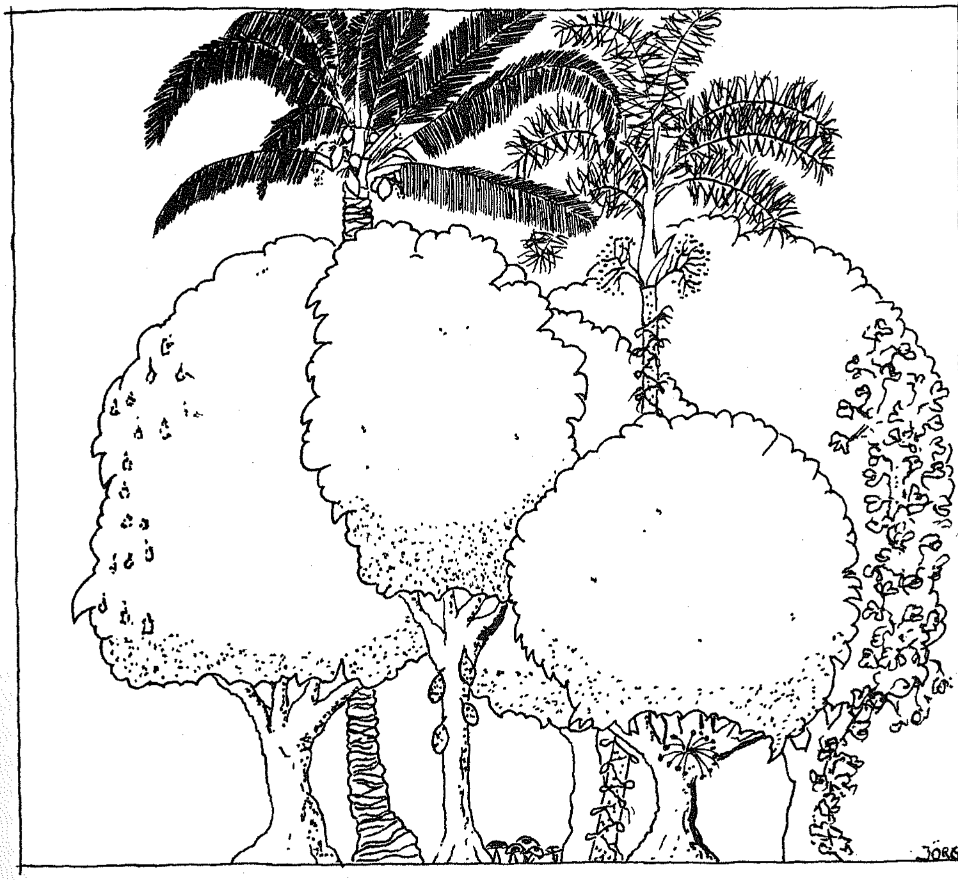
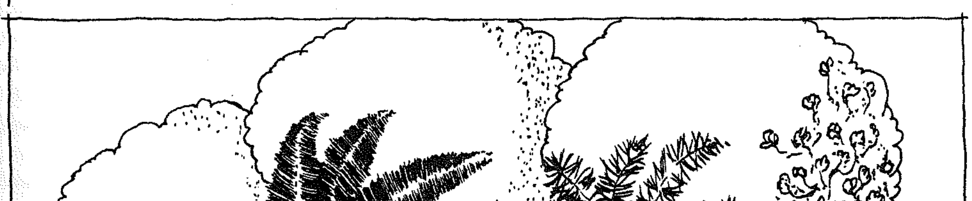


FIGURE 10.45
COMPONENTS OF THE TROPICAL FOREST TREE POLYCULTURE
Palms, lianas (vines), crown–bearers to the outside and stem–bearers inside clumps; fungi and shade species below.
A. Elevation.
[Jörg Schultz].



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.

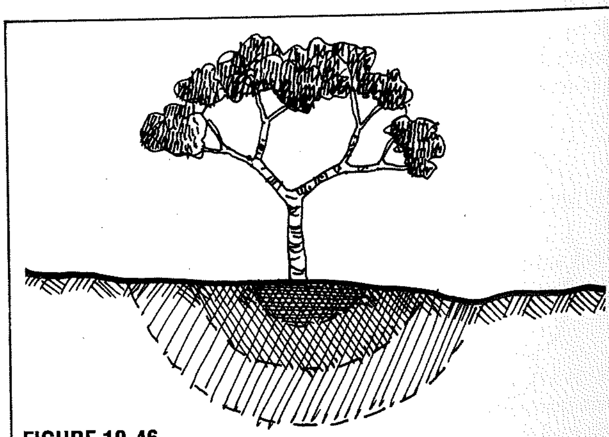


FIGURE 10.46
ZONES OF NITROGEN INTENSITY AROUND A TREE LEGUME.
Nitrogen will diffuse from the soil for up to 6 years after a tree is cut down, so the effects lasts long after the life of the tree. Intensity of nitrogen concentration falls in the outer root zones.

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

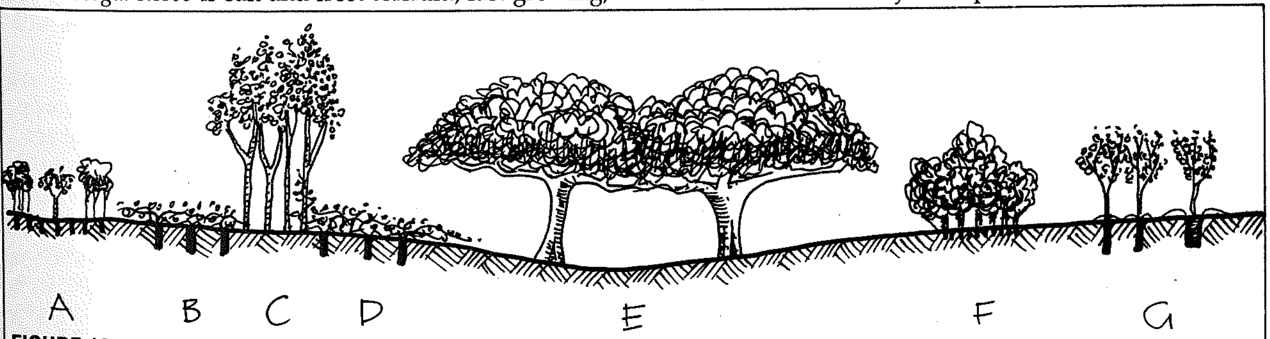


FIGURE 10.47
SAVANNAH FORESTRY.
A. High–value advanced seedlings planted in riplines. **B–D**. Chiselled area sown to Desmodium or lab-lab ground cover. **C**. Acacia strips sown in chiselled ground. **E**. Selected large figs, *Albizia*, *Inga*, set out in good soils around hollows. **F**. *Leucaena* 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.

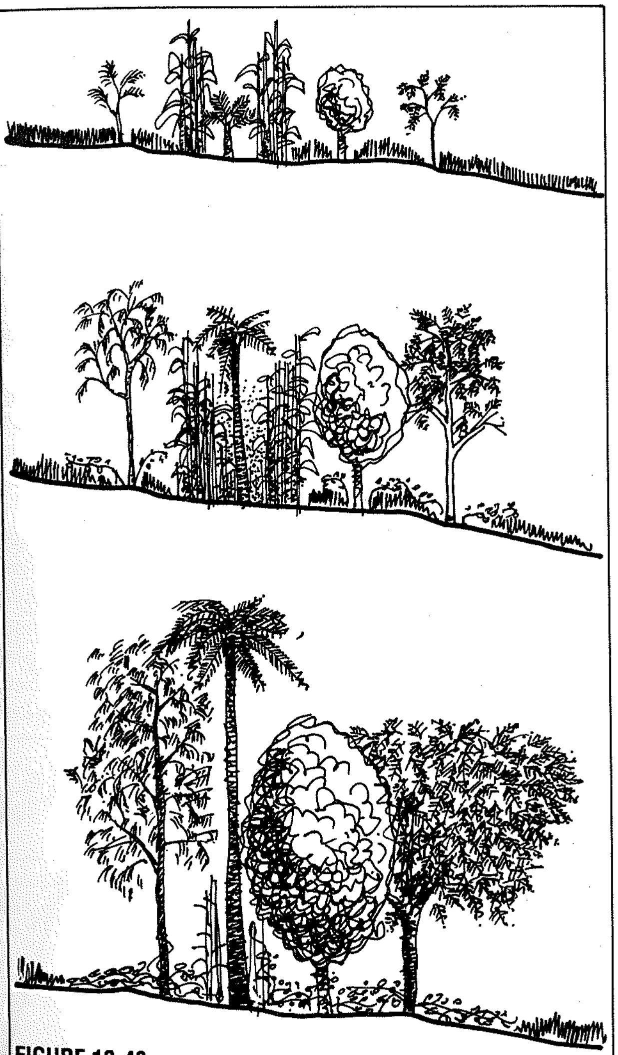


FIGURE 10.48
ROWS OF TROPICAL HEDGEROW AND WINDBREAK.
Evolution from *Pennisetum* hedge to a permanent palm–casuarina–legume windbreak over 2–5 years. Quickset *Erythrina* assists in early establishment as truncheons set in soil.

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**

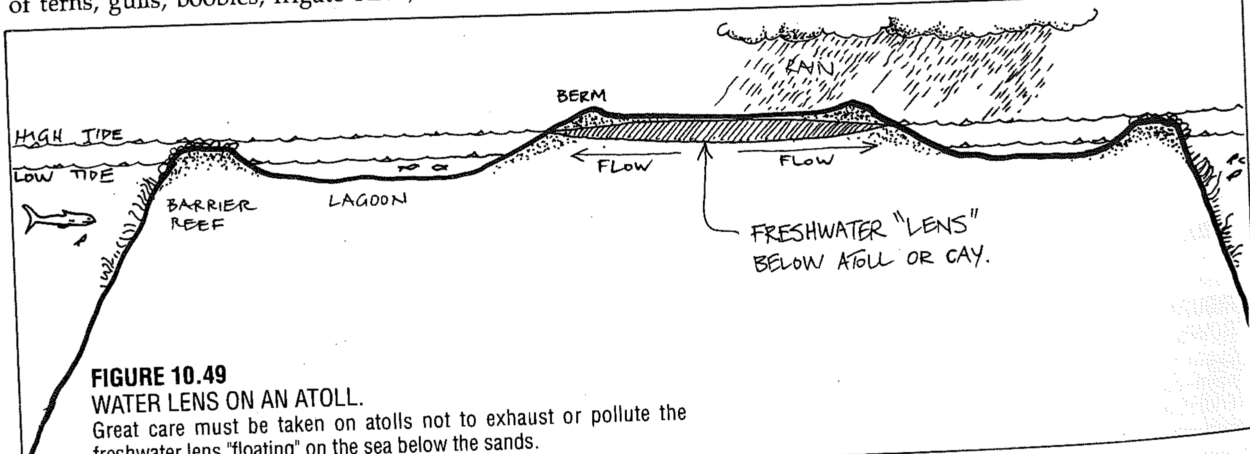


FIGURE 10.49
WATER LENS ON AN ATOLL.
Great care must be taken on atolls not to exhaust or pollute the freshwater lens "floating" on the sea below the sands.

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.

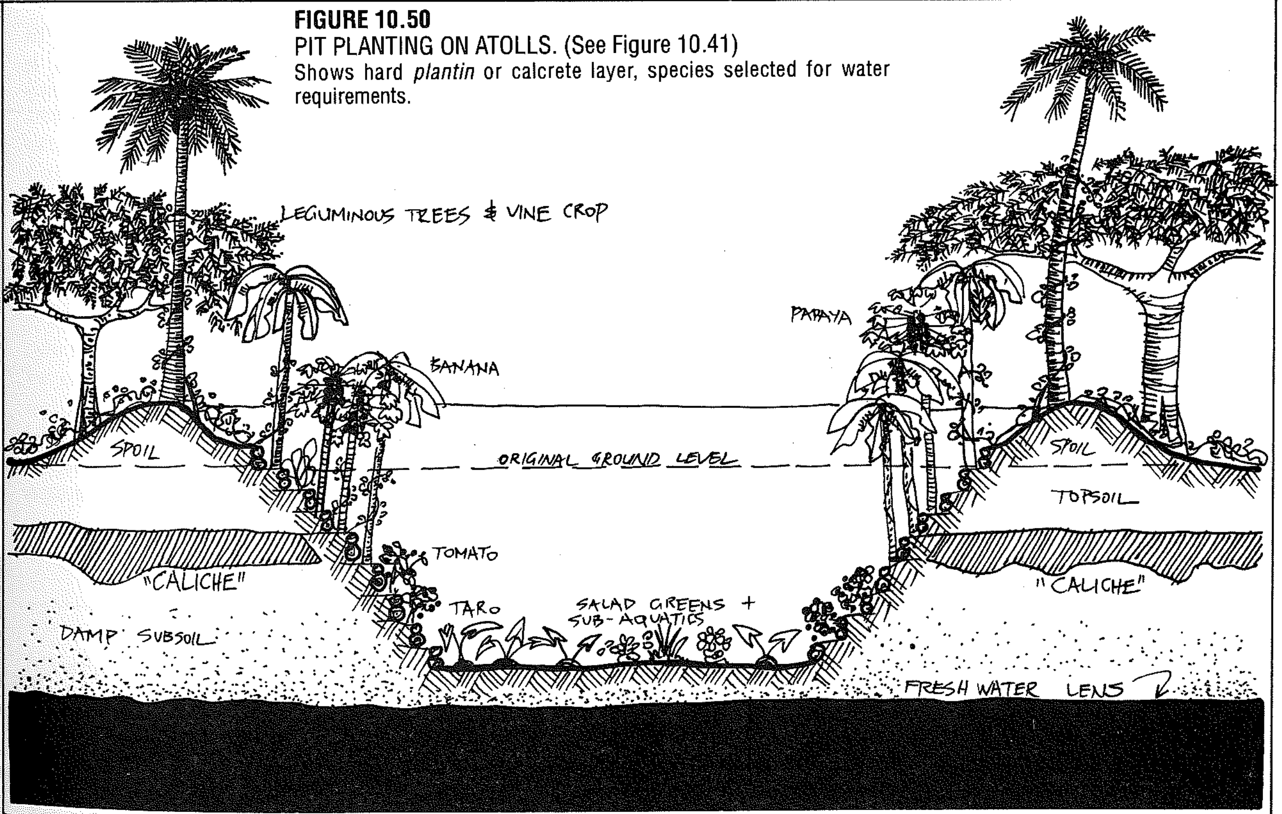
3. SECOND TERRACE(25–60 cm above base). Banana and papaya, sweet potato, cassava (all provide mulch).

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

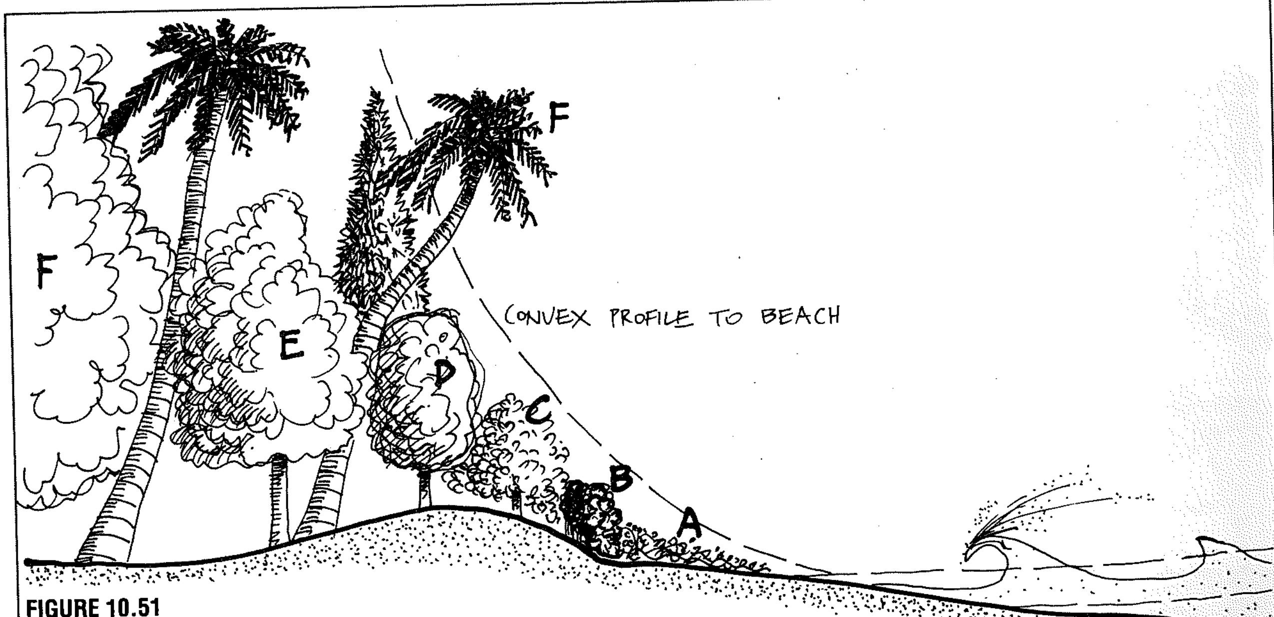


FIGURE 10.51
SEA COAST PLANTING
A. Beach convolvulus. **B**. *Scaevola*. **C**. *Tournefortia*. **D**. *Barringtonia*. **E**. Sea grape (*Coccoloba*). **F**. Date or coconut palm, Casuarina behind beach berm. This profile is stable.

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 overtopped 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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ACKNOWLEDGEMENTS

Many friends have helped with information and trials in tropical areas. I would like to acknowledge data from Bud Driver, Marjorie Spears, John Selman, Michel Fanton, Chuck Busby, Sandy Lewin, Cliff Adam, Imu and Ahela Naki, Richard Waller, Dano Gorsich, Bob Kingswell, and Walter Jehne.