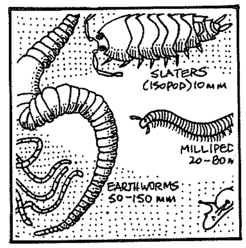

Chapter 8

SOILS

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

8.1 INTRODUCTION

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

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

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

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

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

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

Soils can be RESIDUAL (resting in place over their present rock) or TRANSPORTED by water, ice, gravity, and wind. In their formation the key factors are rock type, climate, and topography (or landform). Water has a key role in rock breakdown, combining with such common minerals as felspars in rock to swell and fracture the rock, then to hydrate the felspars to kaolin, clay, and potassium carbonate. The carbonates released make of soil water a stronger carbonic acid than it is as rain.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Colin Tudge (*New Scientist* '86) muses on the proportion of the British Isles that could be given back to nature. He comes down with a very conservative estimate of perhaps 60%. And at that, without letting go of the misconception that it is agriculture (not individual and market gardening) that will actually provide the future food we eat (a common fallacy). John Jeavons estimates (on the basis of *gardens*) that we could return perhaps 94% of land to its own purposes. Not that I think that we will get there this next decade, but we can start, and our children can continue the process, and so develop new forests and wilderness to explore. A reduction of the ecological deserts that we have called agriculture is well overdue, as is a concomitant reduction in the twin disasters of newspapers and packaging derived from ancient forests.

8.2

SOIL AND HEALTH

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

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

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

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

THE POLLUTION OF SOILS AND WATERS

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

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

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

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

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

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

Several substances have now polluted soils. There are no easy remedies for polluted soils, but the following strategies may help:

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

— Cracked bricks or gravel as a base.

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

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

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

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

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

HUMAN HEALTH AND NUTRITION

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

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

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

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

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

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

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

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

8.3
TRIBAL AND TRADITONAL SOIL CLASSIFICATIONS

From *The Ecologist 14* (4) 1984:

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

• Colour (indicates humus content).

• Taste (agrees with our pH measures).

• Moisture capacity and water retention.

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

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

8.4

THE STRUCTURE OF SOILS

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

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

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

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

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

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

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

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

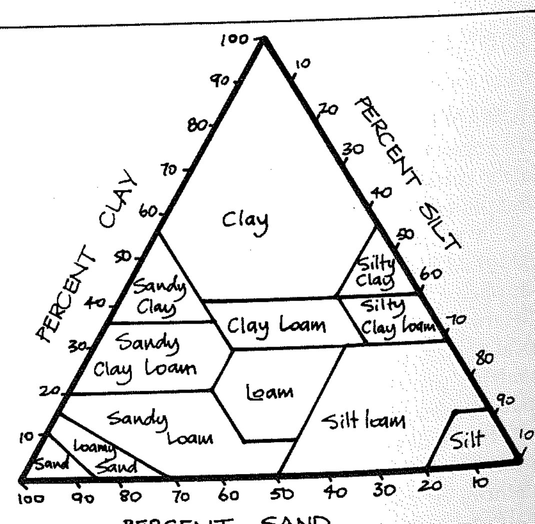

FIGURE 8.1
SOIL PROCESSES.
The USDA classification of soil types by particle size.

8.5
SOIL AND WATER ELEMENTS

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

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

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

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

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

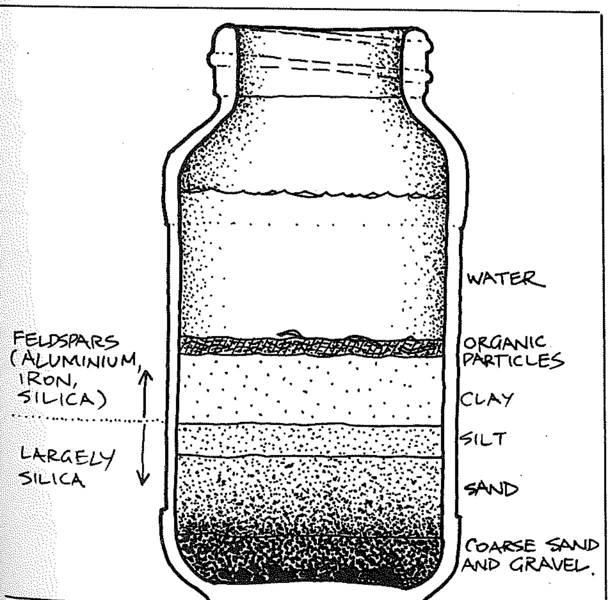

FIGURE 8.2
JAR METHOD
of assessing crude soil composition; useful for classification, uses for mud brick or pisé work. Soil sample is shaken in water and allowed to stand until layers form (1–20 days). The volume of each fraction determines uses and a texture classification (see **FIGURE 8.1**).

8.6
PRIMARY NUTRIENTS FOR PLANTS

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

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

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

SOURCES OF MINERALS IN SOILS

The Sea

It makes sense to assume that as soils are leached, and so made mineral–poor, these minerals later become more concentrated in the sea, in marine organisms, or in inland saltpans. Seaweeds, seagrasses, and fish residues have always been part of agricultural fertilisers, and have maintained their place even in modern times. As seawater evaporates, first calcite and dolomite, then gypsum and anhydrite separate out; all are used for soil conditioning, pH adjustment, or to restore soil crumb structure.

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

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

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

Rocks and rock dusts

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

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

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

8.7 THE DISTRIBUTION OF ELEMENTS IN THE SOIL PROFILE

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

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

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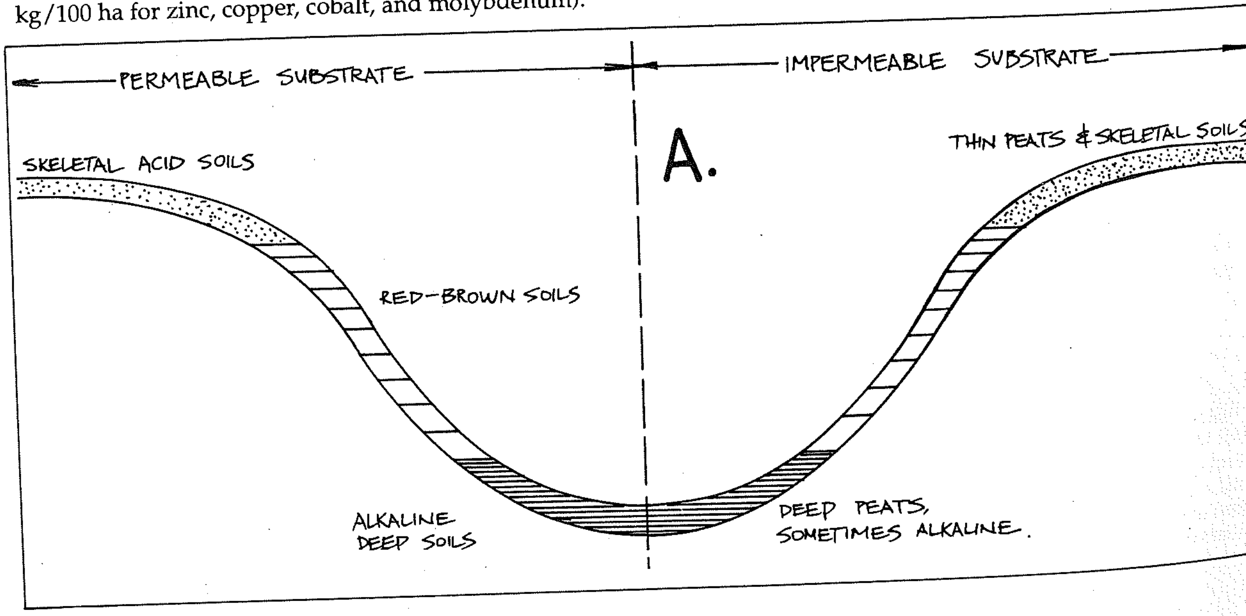

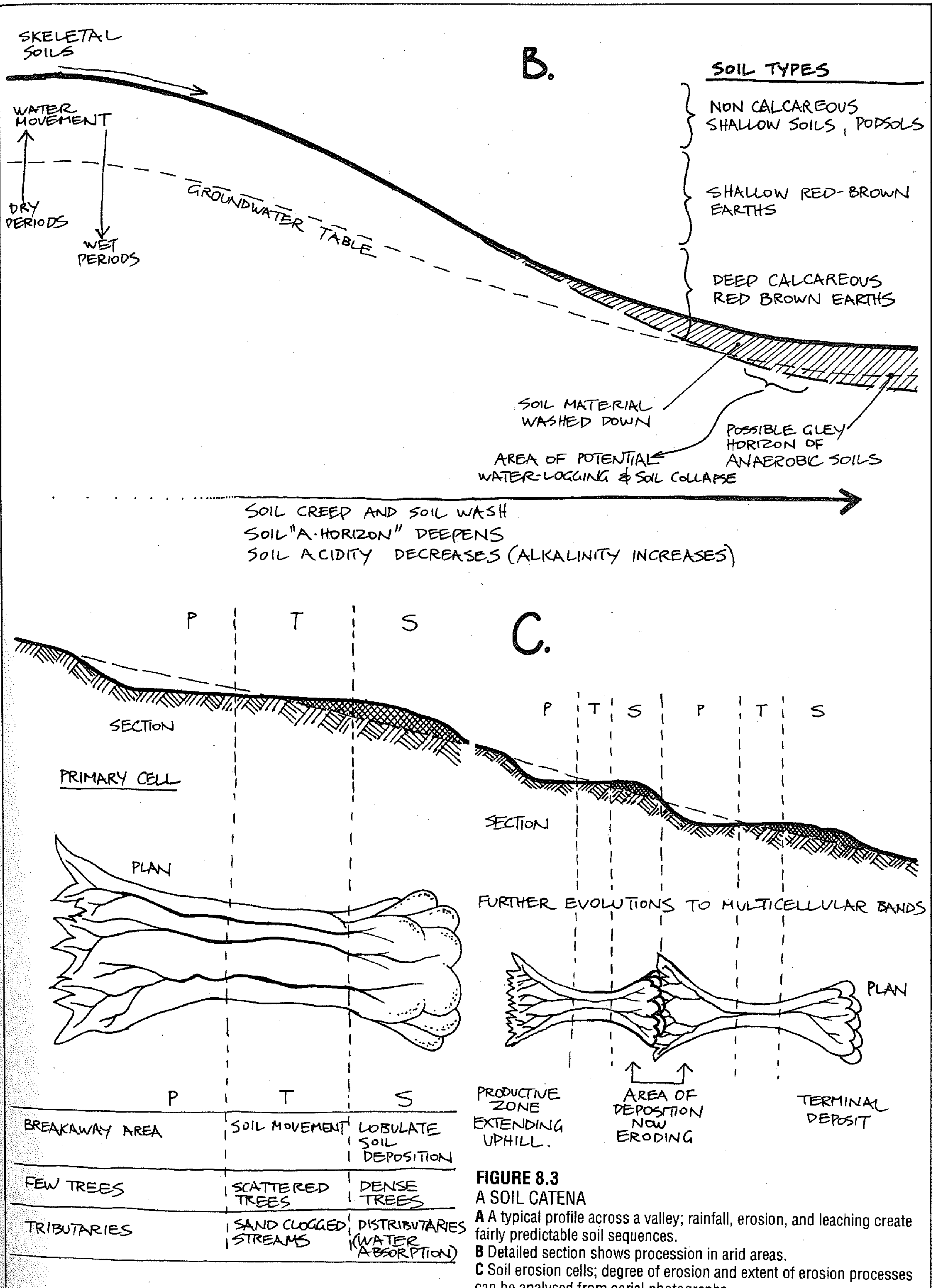

FIGURE 8.3
A SOIL CATENA
A A typical profile across a valley; rainfall, erosion, and leaching create fairly predictable soil sequences.
B Detailed section shows procession in arid areas.
C Soil erosion cells; degree of erosion and extent of erosion processes can be analysed from aerial photographs.

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

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

Hydrogen combines with oxygen as hydroxyl (OH^{2-}) or water (H_20), the basic gaseous and liquid elements. It is the concentration of H^+ or OH^{2-} ions in solutions that decides the pH of soils and water. Hydrogen combined with carbon as methane (CH_4) is emitted by decaying humus in anaerobic (airless) environments such as under water or in compacted or boggy soils. Such soils usually have a mottled profile, and are often bluish, yellow, or contain iron stains and nodules. Methane is a component of marsh gas, or biogas from digesters, usually associated with carbon dioxide and sulphur dioxide (the gases of decomposition). A sulphurous smell in subsoils is a guide to wet–season water–logging, and should be noted for plants intolerant of stagnant waters.

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

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

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

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

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

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

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

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

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

SOME NITRITE (OR NITRATE) LEVELS (ppm):

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- CONCENTRATION BY SELECTIVE SPECIES of fungi, bacteria, and invertebrates which can seek out, assemble, and change specific compounds to stable new forms as concretions or nodules. Iron, iron–manganese, calcium, phosphate, zinc, nickel, copper, selenium, cadmium, phosphate and nitrogen are all so selected and concentrated by one or other form of mycorrhiza (root fungi), bacteria, molluscs, or algae.
- CONCENTRATION BY ACCUMULATION OF DETRITUS. Diatoms, swamp peats, whole forests, sponges (and their spicules of silica), molluscs, and vertebrates are at times buried by vulcanism, sedimentation, or deposition in oceanic deeps to form specifically concentrated sediments, and eventually ore bodies or rock types (coal, rare earths, or manganese deposits).
- DISPERSAL BY TRANSPIRATION. Many water plants seem to be able to dissociate and transpire a great variety of substances to atmosphere. Reeds do this with mercury, hydrogen, and other elements from phosphates to chlorine. Not all of these are vapourised to drift off in the winds; many are deposited in special leaf repositories, or evaporated to a wax, dust, or efflorescence on the leaves and stems of trees, from where they are washed down again to earth by rain throughfall. In this way, both major plant nutrients and minor elements are concentrated in the top 4 cm (1–2 inches) of soil below trees. Metals, oxides, halogens, acids, alkalis and salts are also concentrated.
- CONCENTRATION BY METABOLIC PROCESSES. We build our bodies up by ingesting a large range of complex foods, as do all living things. From these ingested bodies, materials are selected to build our bones, flesh, blood, and brain tissue or organs, nails and hair, fats and milk. Thus, our own bodies and those of other animals are complex storages of elements; even our faeces package very different concentrations of potash, nitrates, and pollutants from the different concentrations of foods that we eat. And, by our behaviours, these are variously disposed of in a personalised, culturally–determined, or species–specific way in the environment. Plants and animals ceaselessly ingest and defecate, refect and exude over their whole lifetimes, thus altering the concentration of nutrients in their immediate environment.

8.8

pH AND SOILS

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

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

ACID AND ALKALINE WATERS AND SOILS

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

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

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

TABLE 8.2
NUTRIENTS IN SOIL AS MINERAL CONTENT.

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

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

and soil constituents are:

- Metals: Sodium, potassium, magnesium, calcium, and minerals (iron, zinc, aluminium, copper).
- Non–metals: Silicon, sulphur, traces of phosphorus, boron, fluorine, chlorides. Carbon is also found in organic soils.

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

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

- CHALK and LIMESTONE are calcium carbonates.
- GYPSUM – calcium sulphate.
- MAGNESITE – magnesium carbonate
- DOLOMITE – calcium magnesium carbonate

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

TABLE 8.4
SOIL AMELIORATION: A BASIS FOR TRIAL PLOTS

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

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

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

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

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

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

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

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

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

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

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

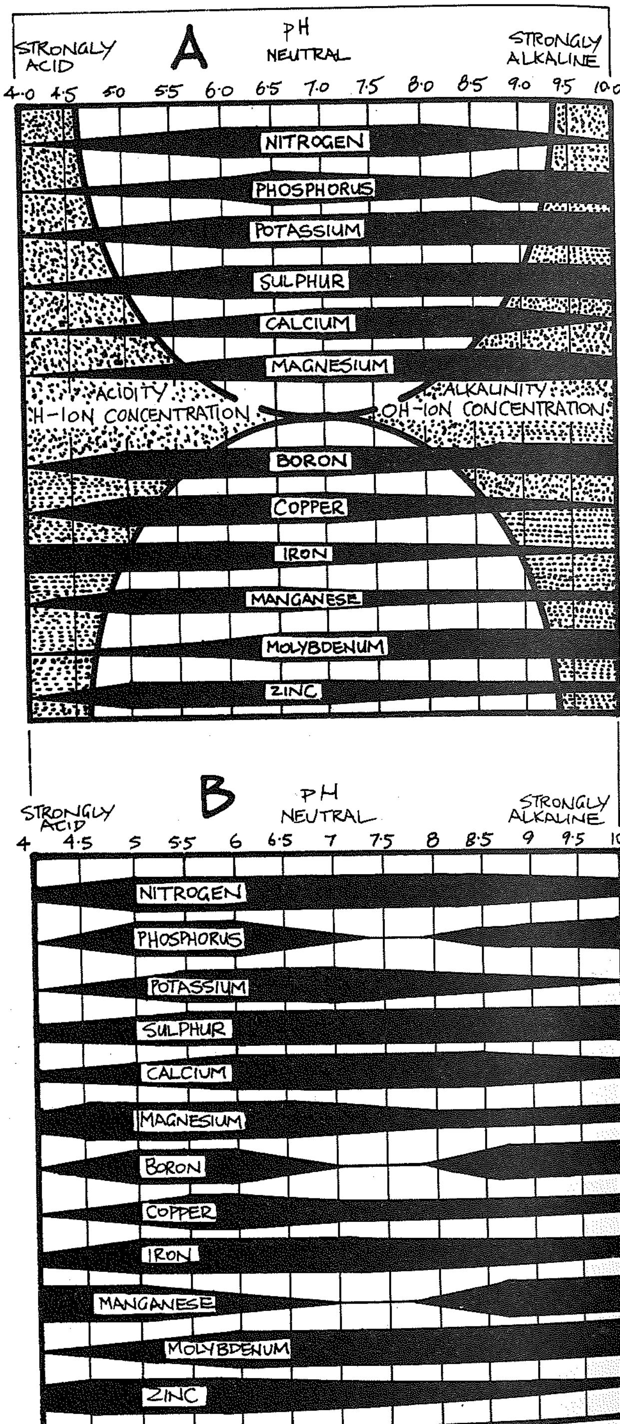


FIGURE 8.4

INFLUENCE OF pH ON AVAILABILITY OF PLANT NUTRIENTS

A In inorganic (mineral) soils. The widest parts of the black areas indicate maximum availability of each element. The curves represent pH values.

[After Nelson, L. B., (Ed.), *Changing patterns of fertiliser use*, Soil Science America, Madison, WI (1968)].

B In organic soils. The widest parts of the black areas indicate maximum availability of each element.

[After Lucas, R. E., amd J. F. Davis, "Relationships between pH values of organic sols and availability of 12 plant nutrients", *Soil Science*, 92:17-182 (1961)] we keep the average pH value to between 4.5 and 10, we can grow a wide range of plants and rear aquatic organisms *if* calcium is present. If we narrow the range to pH 6.0–7.5, most vegetables grow well in gardens. Outside these ranges (less than pH 4.0 or more than pH10.0), only specialised bacteria or higher organisms can cope. Moreover, soil humus is itself a buffer as is calcium (lime); humus will grow plants at satisfactory levels even if the pH changes, so that limed and mulched gardens rarely show plant deficiency symptoms.

8.9
SOIL COMPOSITION

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

THE HUMUS CONTENT OF SOILS

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

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

ORGANIC SOIL ADDITIVES

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

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

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

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

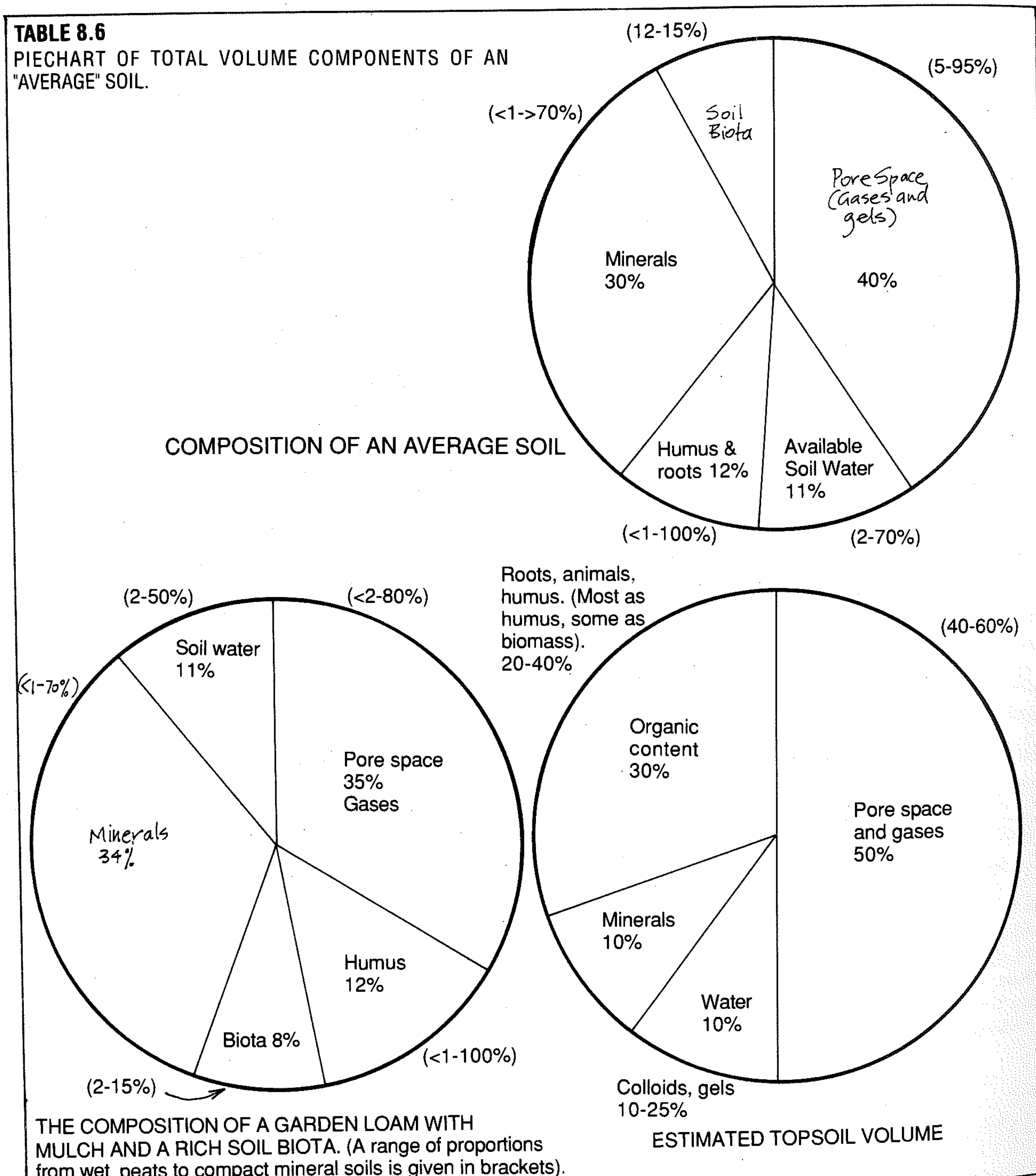
Plastic mulches (black for heat and weed control, silver for aphid repellancy) have a more limited role, important in the short–term, but often expensive or impractical in poor countries, or rejected by growers who suspect that many plastics release persistent chemical polymers of unknown effect on the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

Mulch is an excellent way to add nutrients to soils; the "cool" decay loses little nitrogen, while stimulating soil life generally. There are some problems with compost, where "hot" (aerobic) heaps heat up and nitrogen (ammonia) losses are severe. Cold heaps (pitted or silage) do not lose nitrogen, but neither do they kill weed seeds. One percent of superphosphate added to a hot compost heap prevents ammonia escape. Chinese scientists get the best of both worlds by first building an aerated heap with bamboo poles as holes to create air tunnels. This is then covered with mud and the heap heats up to 55–60°C (130–140°F) for a few days. Then all holes are sealed, and the rest of the decay is anaerobic. With sealed boxes, either hot or cold processes can take place.

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

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

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



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

CARE IN SELECTION OF COMPOST MATERIALS

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

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

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

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

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

8.10

SOIL PORES AND CRUMB STRUCTURE

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

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

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

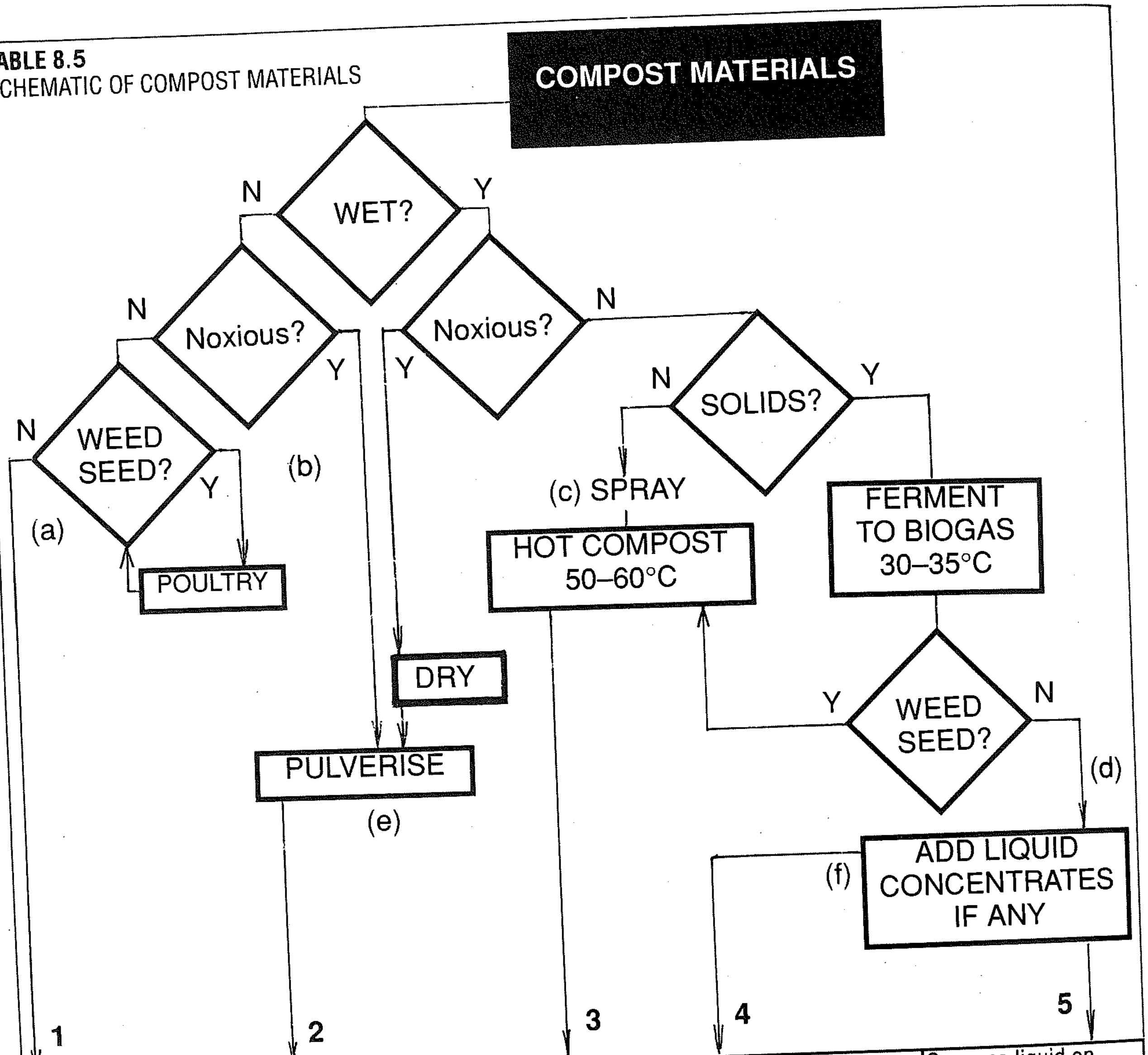
The whole set of disasters outlined above can collapse soils to the cemented, dusty, hydrophobic, salted and desertified areas typical of wheatlands on desert borders. It is a question of improper use, disastrous planning (or no planning), and a total lack of applied goodwill to earth.

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

COLLOIDS AND GELS

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

TABLE 8.5
SCHEMATIC OF COMPOST MATERIALS



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

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

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

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

absorption.

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

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

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

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

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

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

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

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

plastic sheet layer 30 cm below the surface of gardens.

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

Two factors at least affect soil water availability:

- The strength of molecular bonding of water to particles in the soil (ionic bonds). Plant root hairs cannot remove this bound–water at pressures above 15 atmospheres.
- The salt content of the water. Too many salts, and the soil water exerts reverse osmotic pressures on plant roots, and will take water from the roots.

8.11
GASEOUS CONTENT AND PROCESSES IN SOIL

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

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

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

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

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

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

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

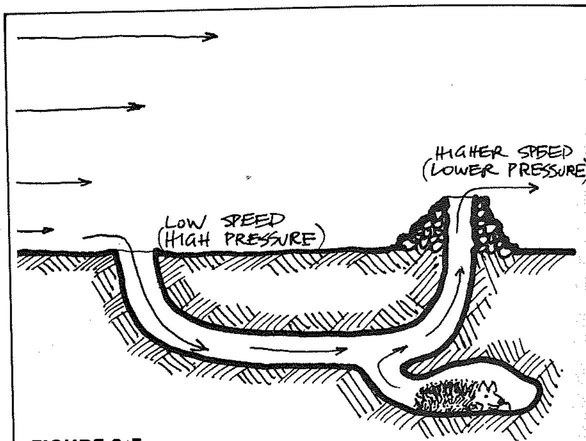


FIGURE 8.5
PITOT TUBE CONSTRUCTED BY A LAND BURROWER
Air flow ventilates burrow and removes waste gases.

GASES MANUFACTURED IN SOILS

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

Ammonia is released from actively nodulating legumes (trees and herbs), and is used in unploughed soils as a plant nutrient. Thus, gaseous compounds are continually made in the soil itself by process of metabolic growth and decay in the presence of metallic catalysts and micro–organisms. Moybdenum, vanadium, and zinc all assist root bacteria in the creation of available soil nitrogen (as catalysts).

GASEOUS MOSAICS OVER TIME;
SOIL MICRO–SITES

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

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

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

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

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

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

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

8.12
THE SOIL BIOTA

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

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

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

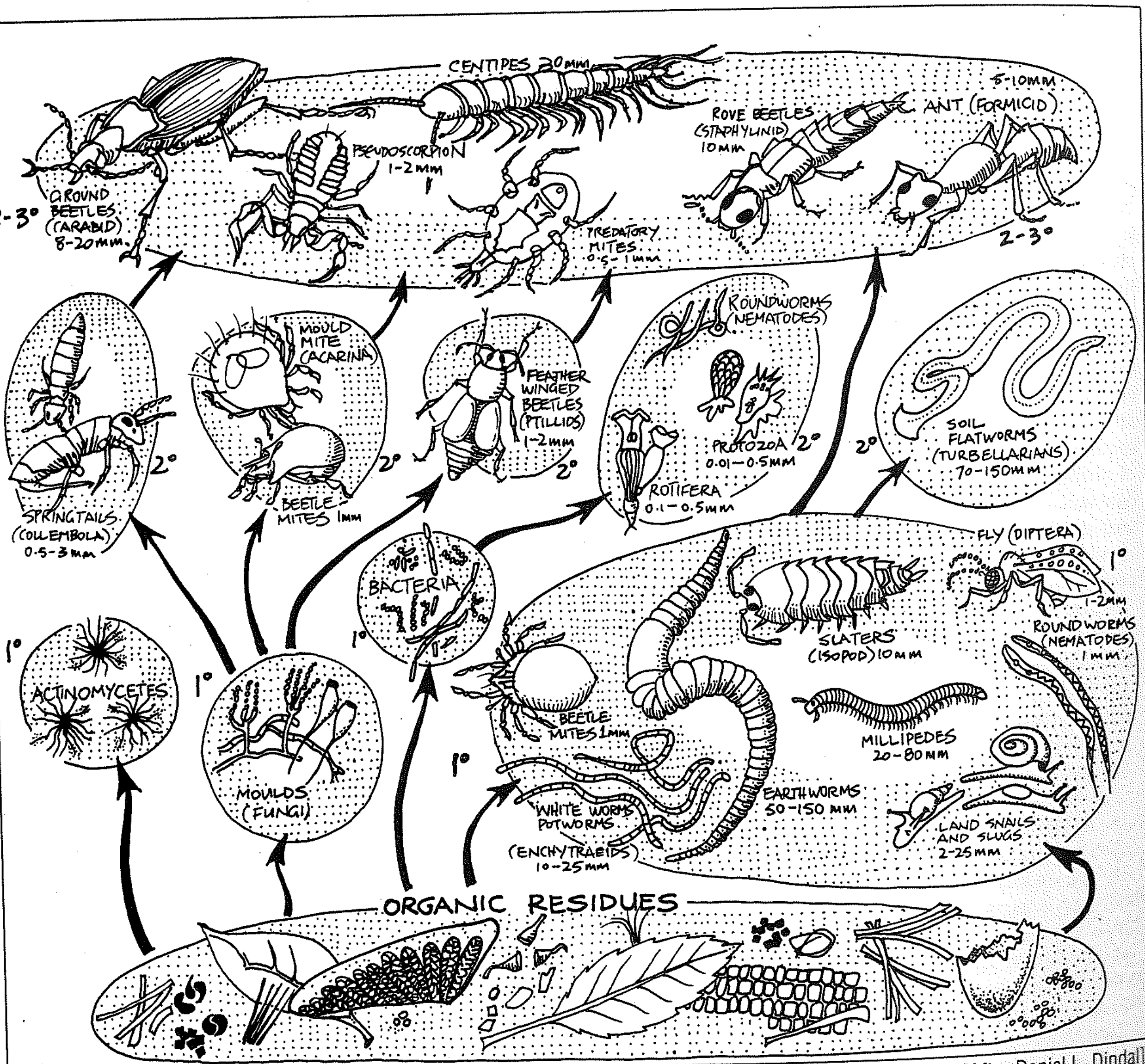
A wheat field is not the place most likely to produce high levels of soil biota, and plough cropping has (in Canada) reduced humus levels to 1% of the original levels over much of the wheat country.

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

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

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

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



[After Daniel L. Dindal]

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

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

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

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

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

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

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

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

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

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

EARTHWORMS

> Worms have played a more important part in the history of the world than most persons would at first suppose. In almost all humid countries they are extraordinarily numerous, and for their size possess great muscular power. In many parts of England a weight of more than ten tons (10,516 kg) of dry earth annually passes through their bodies and is brought to the surface on each acre of land; so that the whole superficial bed of vegetable mould passes through their bodies in the course of every few years... Thus the particles of earth, forming the superficial mould, are subjected to conditions eminently favourable for their decomposition and disintegration...
>
> The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures.
>
> (Charles Darwin, *The Formation of Vegetable Mould Through the Action of Worms*, 1881)

From the time of Darwin (and probably long before), copious worm life in soils has been taken as a healthy sign, and indeed more modern reviews have not reversed this belief (Satchell, 1984). Worms rapidly and efficiently recycle manure and leaves to the soil, keep soil structure open, and (sliding in their tunnels) act as an innumerable army of pistons pumping air in and out of the soils on a 24-hour cycle (more rapidly at night).

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

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

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

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

8.13

DIFFICULT SOILS

CONCRETIONS AND PANS

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

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

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

- SILCRETE (*cangagua*) is a grey to red shiny hard layer developed below some tropical forest soils, which gives a glassy surface if forests are cleared. The soil is concreted by silica deposits. If such deposits lie below forests, it is unwise to clear the forest itself. Durian: Silica-cemented non-wetting horizon, earthy, brittle, found only in volcanic areas. Red-brown hardpan: occurs in many soil types, not volcanic, semi-arid, and is 10 cm–30 m (4 inches to 98 feet) thick.
- FERRICRETE: Iron-cemented pans and soil layers of varying thickness, sometimes as thin sandy layers of 5–10 mm; also alumina-iron laterites (often capping desert hills with veins of silcrete) or iron-manganese nodular horizons in soils. Ferricrete may lie over pale bauxites, and is also called ironstone, plinthite. Ortstein occurs in podzols as iron-organic hard B horizons. Coffeerock is a thick sandy coffee-coloured horizon, low in iron and easily broken; it is a common horizon in humic podzols. Duricrusts form hard silica-iron caps on hills in deserts.
- PLOUGH PANS are usually clay-based compacted layers developed below croplands in wet periods; these can be caused by mouldboard ploughs.

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

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

NON-WETTING SANDS AND CLAYS

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

- Ridge soil to make basins.

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

- Compost thoroughly and build up organic material to 8% of surface soil.
- Add a handful of bentonite per square metre, or powdered clay from clay pans.
- Mulch thoroughly, and plant. Keep surface mulch

supplied.

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

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

• Make low banks across run–off.

• Add gypsum at 2–3 handfuls per square metre, and if possible flush out with fresh water (removing sodium as sulphate).

• If practical, place sand over the surface to 4 cm deep.

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

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

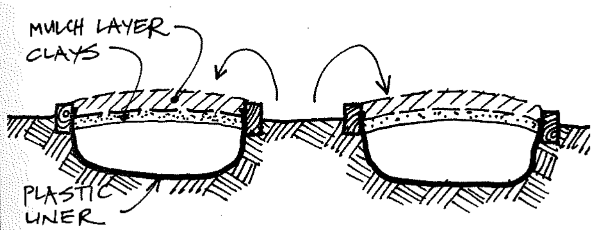


FIGURE 8.7
LAYING PLASTIC IN DEEP SANDS
Plastic sheet prevents deep leaching , clays hold water at root level; mulch prevents surface evaporation.

8.14

PLANT ANALYSIS FOR MINERAL DEFICIENCIES; SOME REMEDIES

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

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

2. VERY DIFFERENT BEHAVIOUR OF NUTRIENTS:

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

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

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

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

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

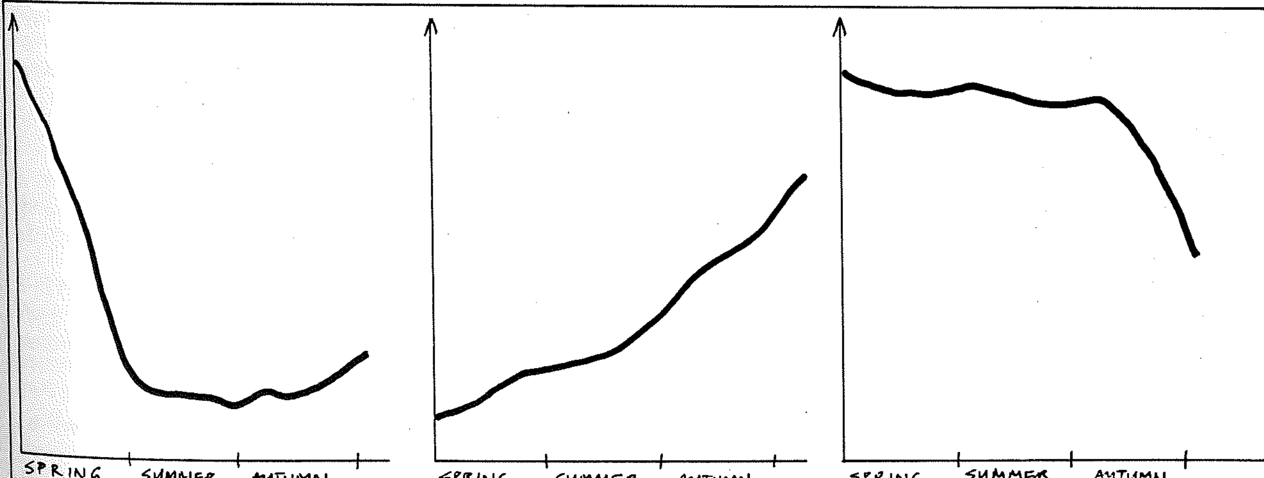


FIGURE 8.8
A 'TYPOLOGY' OF THE ELEMENTS IN LEAF TISSUE (in winter, trees are bare).
Behaviour of basic nutrients in the leaf analysis of a deciduous tree (here a persimmon). Levels vary across the growing season.
[After *GrowingToday*, NZ Tree crops Association, Feb. 1986 (See pp16–7 for actual graphs)].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

TABLE 8.7
KEY TO MINERAL DEFICIENCIES

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

First Choices: **Go to**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

REMEDIES FROM THE KEY
(FOR GARDENS)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

{12} Phosphorus. Bring pH to 6–6.5 or thereabouts, using lime in acid soils and humus in alkaline. Use bone meal, bury bones, or use tested rock phosphate free of cadmium or uranium. **Stop deep digging** and start mulching with least soil disturbance (build up narrow beds). Encourage soil life, add mulch on top, water with comfrey "tea", dilute bird manure on the **leaves** of plants. Keep this up each time symptoms appear; they will eventually disappear if you have clay in the beds (add some if not). If you have high–iron clays, you will need a lot of bone meal to start with, but it will slowly release later on. If desperate, use a few handfuls of superphosphate per square metre, then continue with other sources. Feed a patch of comfrey with bird manure and make a comfrey tea in a drum of cold water. Water the plants with this. All animal manures (including yours) contain some phosphorus. Calcined (roasted) rock phosphate is effective on acid soils in high rainfall.

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

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

MINERAL FERTILISERS OR SOIL AMENDMENTS

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

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

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

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

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

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

8.15

BIOLOGICAL INDICATORS OF SOIL AND SITE CONDITIONS

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

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

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

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

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

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

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

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

Alkaline intolerant (pH 4.5–6.0):
- Blueberry
- Chicory
- Chestnut
- Endive
- Potato
- Fennel
- Tea
- Coffee
- Rhubarb
- Shallot
- Watermelon

Alkali tolerant:
- Oats
- Kale
- Rye

Acid intolerant (pH 7.0–8.5):
- Cauliflower
- Cabbage
- Asparagus
- Green peas, bush beans
- Celery
- Leek
- Beet
- Onion
- Chard
- Parsnip
- Spinach
- Lucerne
- Broccoli

Acid tolerant:
- Lupin
- Oats
- White clover

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

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

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

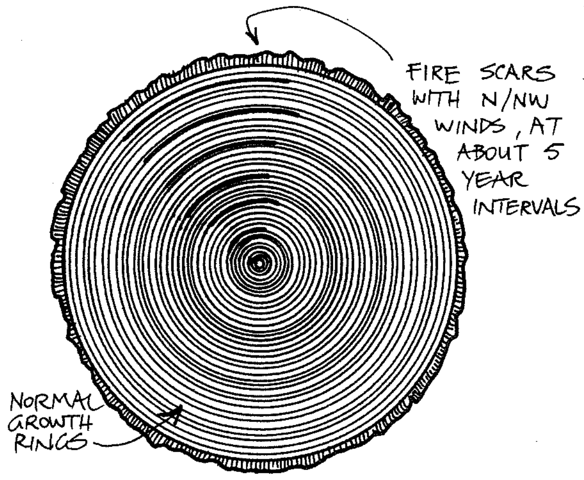


FIGURE 8.9
FIRE DIRECTION SCARS ON TREE RINGS
Show frequency and severity of fires on any one site.

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

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

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

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

General plant ash analysis may reveal more *specific* plant–ore associations. This has further implications for the rehabilitation of mine waste areas, and also to select plant sources for the supply of trace minerals in compost. As plants have the ability to both concentrate and tolerate unusually high levels of specific minerals, there seems to be a field here for the biological concentration (and subsequent removal) of metallic soil pollutants like lead or uranium, and the use of concentrator plants to mine or collect locally rare trace elements. In fact, some patents have apparently been granted for mining gold deposits using banana or citrus plants deprived of some common elements (potash, phosphate); their leaves then concentrate sparse deposits of gold.

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

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

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

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

8.16
SEED PELLETING

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

- SEED PRETREATMENT. If seeds have thick coats, or need heat or cold treatment or scarification to break dormancy, they must be treated before pelleting.
- INOCULATION. Purchase and inoculate legume seed with their appropriate microbial or fungal spores. Soak the seed in inoculant solution, then dry the seed. Mix dried seed with a primary coat as below.
- PELLETING. Use a lime, clay layer, and a trace of fine rock flour, calcium, or phosphate mixed into a damp but plastic slurry around the seed. This is then extruded (e.g. via a meat mincer with the cutting blades removed) to a shaker table or tray covered with dust, and on a slight incline. Dust is added as needed to dry and shape the pellet, or to set a desirable size of pellet (**Figure 12.18**).

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

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

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

8.17
SOIL EROSION

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

- Via wind: by dust storm and the blow–out of dunes and foreshores.
- Via water flow by sheet erosion (a generalised surface flow off bare areas and croplands), gully erosion (caused by concentrated flow over deep but unstable sediment), and tunnel erosion (sub–surface scouring of soils below).
- Via soil collapse or deflocculation following increased salt concentrations in clay–fraction soils.

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

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

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

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

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

8.18

SOIL REHABILITATION

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

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

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

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

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

TABLE 8.8
Improvement in Crumb Structure

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4. CROP AND PLANT SPECIES SELECTION. Many older varieties of both annual and perennial crops will yield with less fertiliser and water applications than will more recently–developed varieties. There is a growing trend amongst farmers and gardeners to preserve and cultivate these varieties not only for the reasons above, but also for flavour. Many older apple varieties, such as some of the Pippin and Russet types, are more flavourful than, say, the market–variety Red Delicious. There is still a large diversity of food crops left in the world; the key is to grow them and to develop a regional demand. Many older apple or wheat species are not only pest–resistant, but have higher nutritive value, and can produce well in less than optimum conditions.

There are different species of plants that can live in almost any type of soil, starting the process back to rehabilitation. It is often the case that so–called noxious weeds will colonise eroded landscapes, beginning a slow march towards stabilisation; these can be used as mulches.

Soils can be created or rehabilitated by these basic methods:

- Building a soil (at garden scale);
- Mechanical conditioning; and
- Life form management (plants and macro– or micro–fauna).

BUILDING A SOIL

Gardeners normally build soil by a combination of

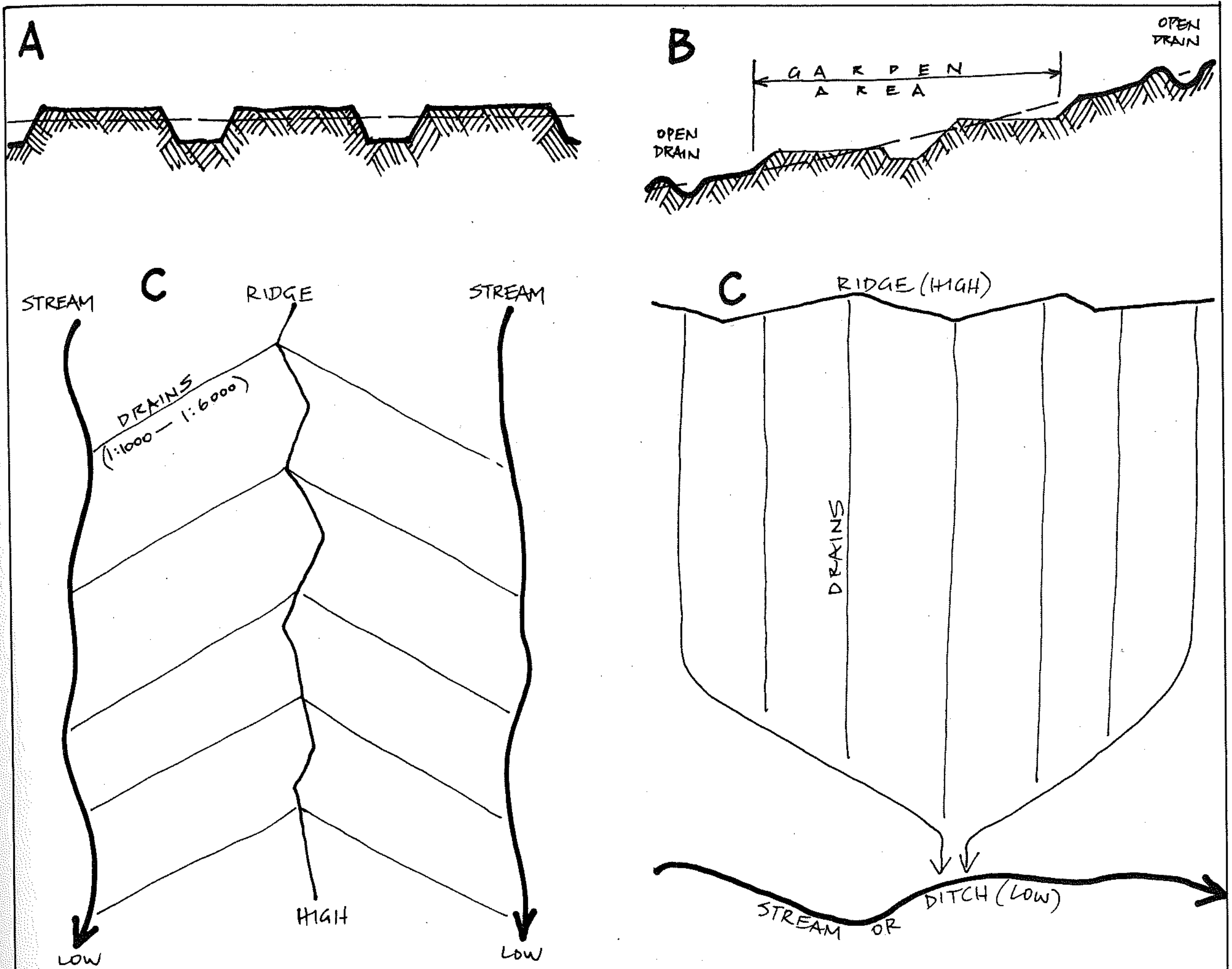


FIGURE 8.10
DRAINAGE OF WET SOILS
A Raised garden beds
B Deep open drains
C Underground pipes or ditches at about 1:200 slope will drain fields.

three processes:

1 Raise or lower beds (shape the earth) to facilitate watering or drainage, and sometimes carefully level the bed surface;

2 Mix compost or humus materials in the soil, and also supply clay, sand, or nutrients to bring it to balance; and

3 Mulch to reduce water loss and sun effect, or erosion.

Gardeners can, by these methods, create soils anywhere. Accessory systems involve growing such compost materials as hedgerow, herbs, or soft–leaf plots, or as plantation within or around the garden, and by using a combination of trellis, shadecloth (or palm fronds), glass–house, and trickle irrigation to assist specific crops, and to regulate wind, light, or heat effect.

By observing plant health, gardeners can then adjust the system for healthy food production. Many gardeners keep small livestock, or buy manures, for this reason.

Large–scale systems (small farms) cannot be treated in the above way unless they are producing high–value product. Normally, farmers create soils by broadscale drainage or by soil "conditioning". As most degraded soils are compacted, eroded, or waterlogged, they need primary aeration (by one of the many available modern machines, or by biological agents), then careful plant and livestock management to keep the soil open and provided with humus.

Daikon radish, tree or shrub legumes, earthworms, root associates for plants (rhizobia) all aerate, supply soil nutrient, or build soil by leaf fall and root action. The management of livestock for least compaction and over–grazing is part of the skill of soil building and preservation. Many organic farmers introduce worm species to pastures as part of their operation, and sow deep–rooted chicory, radish, or comfrey for green manures.

SOIL TREATMENT ON COMPACTED SITES—
SOIL CONDITIONING

On the common degraded soils of marginal areas, we can observe compacted, eroded, lifeless soils; they are overgrazed and often invaded by flatweeds and non–forage species of plants. They are boggy and wet in winter, and they are dry, cracked and bony in summer, having little depth. The reconstitution proceeds as follows:

At the end of winter, or in autumn after some rain, when the soil will carry a tractor, a chisel plough is pulled 5–10 cm (2–4 inches) deep over the area, either on contour parallels or on low slopes, starting in the high valley bottoms and driving slightly downhill to the ridges. Unless there are absolutely no legumes or grasses already growing, no extra seed is applied. The response is increased penetration of roots, germination of seed, and a top–growth of pasture.

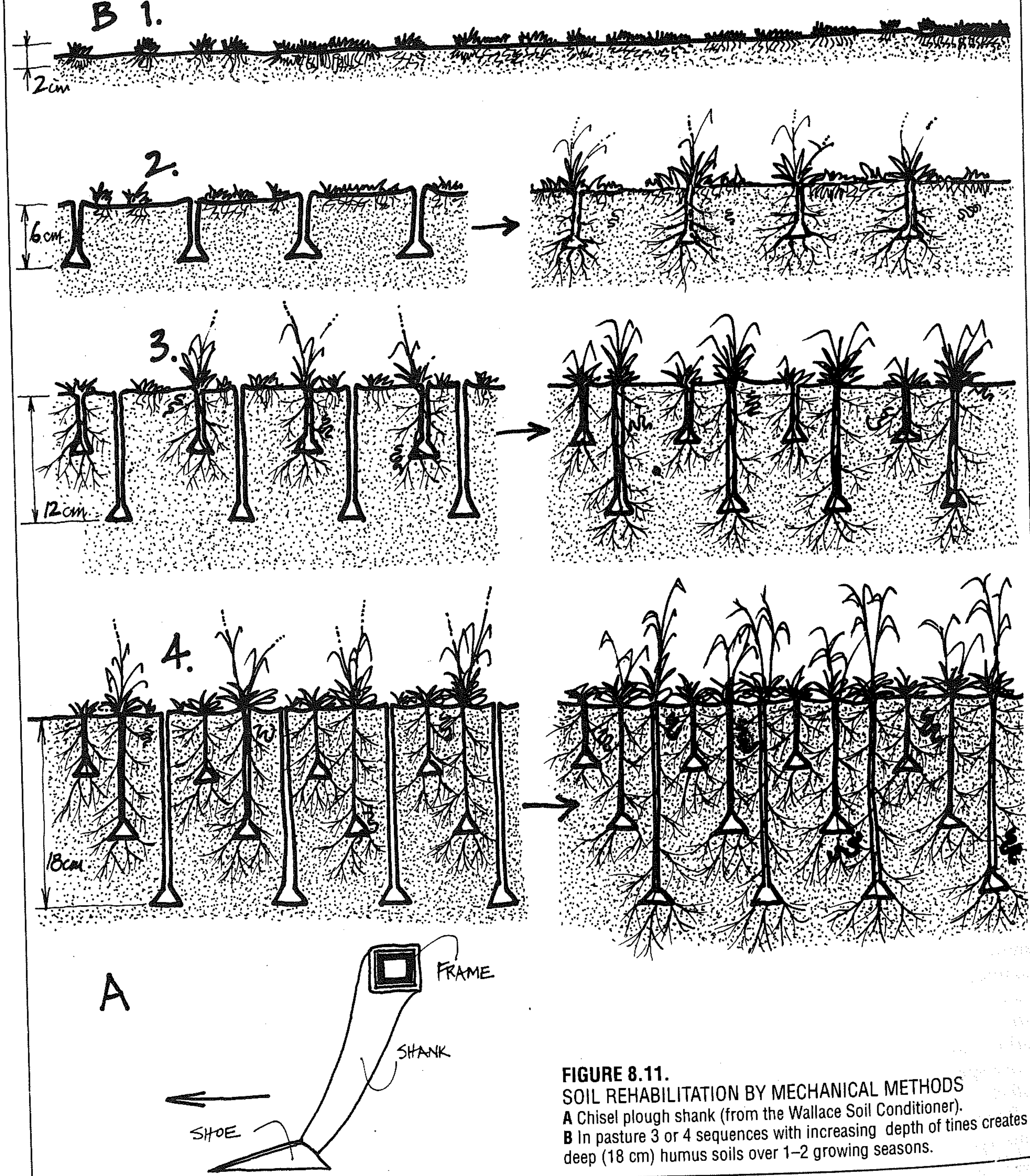


FIGURE 8.11.
SOIL REHABILITATION BY MECHANICAL METHODS
A Chisel plough shank (from the Wallace Soil Conditioner).
B In pasture 3 or 4 sequences with increasing depth of tines creates deep (18 cm) humus soils over 1–2 growing seasons.

A chisel plough or soil conditioner is a rectangular steel frame (tool bar) towed by tractor or draught animals, to which a number of shanks are attached. These are narrow–edge (axe–edged) forward–curved vertical flat bars to the point of which a slip–on steel shoe is attached. The shanks clamp to the tool–bar frame, and the points to the shank. Even one implement of 5 shanks (25–50 b.h.p. tractor) covers a lot of country. There are now at least six or seven makers of soil–loosening machines, in the USA, Europe, and Australia.

Geoff Wallace has produced a soil conditioner of great effectiveness. A circular coulter slits the ground, which must be neither too dry nor too wet, and the slit is followed by a steel shoe which opens the ground up to form an air pocket without turning the soil over. Seed can be dropped in thin furrows, and beans or corn seeded in this way grow through the existing grass. No fertiliser or top–dressing is needed, only the beneficial effect of entrapped air beneath the earth, and the follow–up work of soil life and plant roots on the re–opened soil.

This new growth is then hard–grazed, or cut and left to lie. The plants, shocked, lose most of their root mass and seal their wounds. The dead roots add compost to the soil, as does the cut foliage or animal droppings, giving food to the soil bacteria and earthworms, and softening the surface. As soon as the grazing or cutting is finished, chisel again at 23–30 cm (9–12 inches), on the same pattern as before. Graze or cut again, chisel again at 23–30 cm. Graze or cut.

During this process, often a matter of a one–year cycle, the pasture thickens, weeds are swamped with grasses and legumes, myriad roots have died and added humus, and thousands of subsurface tunnels lead from valley to ridge, so that all water flows down into the soil and out to the ridges. Earthworms breed in the green manure, bacteria multiply, and both add manures and tunnels to the soil. A 23 cm (9 inch) blanket of aerated and living soil covers the earth.

Dust, deep roots, rain, and the bodies of soil organisms all add essential nutrients. The composted soil is, in essence, an enormous sponge which retains air and water, and it only needs a watchful eye and an occasional chiselling in pasture (or a forest to be planted) to maintain this condition.

If tree seed, soybeans, millet or other crop is to be planted, the sequence is as follows: after a few hard grazings or mowings, a seed box is mounted on the chisel plough frame, and the seed placed in the chisel furrow; the grazing or mowing follows germination of the seed. These new plants (sunflowers, millet, melons) grow faster than the shocked pasture, and can be let go, headed, or combine–harvested before the grasses recover. There is never any bare cultivation, and grain growers can move to a minimum tillage method of cropping, with fallows of pasture between crops.

Soil temperature is greatly modified, as is soil water retention. Geoff Wallace (*pers.comm.*) recorded as much as 13°C (25°F) increase on treated versus untreated soils in autumn. This increased temperature is generated both by the biological activity of the soil and the air pockets left by the chisel–points at various depths, and enables earlier and more frost–sensitive crops to be grown.

Nodulation (of nitrogen–fixing bacteria) is greatly increased, as is the breakdown of subsoil and rock particles by carbonic acid and the humic acids of root decay. Methane generated from decay aids seed germination, and water (even in downpours) freely passes into, not off, the soil. After a year or so, vehicles can be taken on the previously boggy country without sinking in. Drought effects are greatly reduced by soil water storage.

Water, filtered through soil and living roots, runs clear into dams and rivers, and trees make greatly increased growth due to the combined factors of increased warmth, water, root run, and deep nutrients.

Fukuoka(3) (in Japan) uses radish and *Acacia*; Africans use *Acacia albida* or *Glyricidia*; New Guineans use *Casuarina*; and Mediterranean famers use *Tamarix* for biological "chisel ploughs" where land is too steep and stony for implements. Otherwise the "graze or cut and let lie" method is still followed. On such difficult terrain as boulder fields, dunes, steep slopes, and laterites, forests of mixed legume/non–legume crops (citrus, olive, pine, oak) are the best permanent solution to soil conservation.

No matter how we aerate soil (or condition it), whether with humble implements like a garden fork levered slightly, by planting a daikon radish, or by sheer mechanical power, we can soon lose the advantage of looseness and penetrability by over-stocking, cropping, heavy traffic, or heavy–hooved animals stocked in wet weather. All of these pug or compress the soil into a solid state again. Final solutions lie only in following on with permanent and deep–rooted plants (forests or prairies), and by maintaining good management (minimum tillage) cropping.

Any reduction in cultivation saves energy and soils, and wherever no–tillage systems can be devised, and heavy hoofed animals kept to a minimum, soil structure can be repaired.

Intense fire, intense stocking, intense cropping, and intensive production all threaten soils. Thus, mechanical soil rehabilitation can be a one–time and beneficial process, or another way to waste energy every year. It is the usages that follow on re-habilitation that are beneficial or destructive to soils in the long term.

Mechanical loosening of soils is appropriate (on the broad scale) to almost all agricultural soils that have been compacted. Soils with coarse particles, of cinder, or dunes do not benefit from or need loosening, and very stony or boulder–soil mixtures are appropriately rehabilitated not by mechanical but by organic (root penetration) methods, as are soils on steep slopes. Some soils (like volcanic soils with permanent pastures) may never lose structure, and will maintain

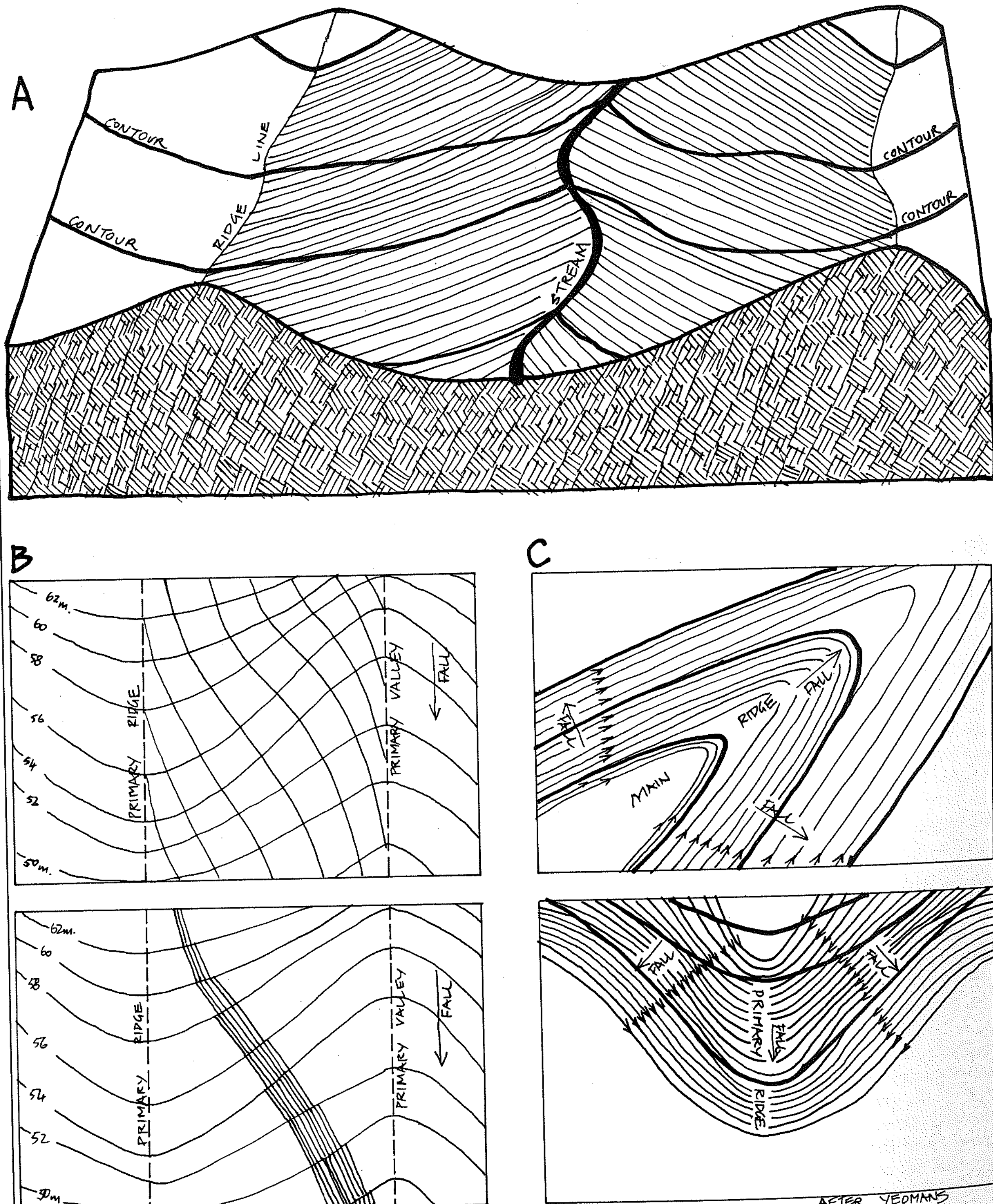


FIGURE 8.12
SOIL CONDITIONING
A Ideally, chisel lines run "downhill" from valley to ridges.
B Here, water flow crosses contours at right angles (no chisel lines) and creates sigmoid (S) curves in the landscape.
C In conditioned landscapes, chisel lines prevent fast run–off and absorb overland flow, leading water to ridges.

free internal drainage after years or centuries of grazing. Thus, we use rehabilitative energy only where it is appropriate.

Soil conditioning can be sequential, allowing a year between treatments, or all–at–once at 20 cm or so, in order to prepare for tree crop planted immediately. The time to use implements is also critical, and early spring or at the end of a gentle rainy period is ideal, as the soil is not then brought up to the surface as dry clods, nor collapses back as being too wet.

There is only one rule in the pattern of this sort of ploughing and that is to drive the tractor or team slightly downhill, making herring–bones of the land: the spines are the valleys and the ribs slope out and down–slope (**Figure 8.12**). The soil channels, many hundreds of them, thus become the easiest way for water to move, and it moves *out* from the valleys and below the surface of the soil. Because the surface is little disturbed, roots hold against erosion even after fresh chisel ploughing, water soaks in and life processes are speeded up. A profile of soil conditioned by this process is illustrated by **Figure 8.11**.

There is no point in going more than 10 cm in first treatment, and to 15–23 cm in subsequent treatments. The roots of plants, nourished by warmth and air, will then penetrate to 30 cm or 50 cm in pasture, more in forests. For disposal of massive sewage waste–water, Yeomans[5] recommends ripping to 90 cm or 1.5 m, using deep–rooted trees or legumes to take up wastes.

I have scarcely seen a property that would not benefit by soil conditioning as a first step before any further input. Pasture and crop do not go out of production as they do under bare earth ploughing with conventional tools, and the life processes suffer very little interruption.

In small gardens, the aeration effect is obtained in two ways:

- By driving in a fork and levering gently, then removing it.
- By thick surface sheet–mulch; worms do the work.

To summarise briefly, the results of soil rehabilitation are as follows:

- Living soil: earthworms add alkaline manure and act as living plungers, sucking down air and hence nitrogen;
- Friable and open soil through which water penetrates easily as weak carbonic and humic acid, freeing soil elements for plants, and buffering pH changes;
- Aerated soil, which stays warmer in winter and cooler in summer;
- The absorbent soil itself is a great water–retaining blanket, preventing run–off and rapid evaporation to the air. Plant material soaks up night moisture for later use;
- Dead roots as plant and animal food, making more air spaces and tunnels in the soil, and fixing nitrogen as part of the decomposition cycle;
- Easy root penetration of new plantings, whether these are annual or perennial crops; and
- A permanent change in the soil, if it is not again trodden, rolled, pounded, ploughed or chemicalised into lifelessness.

Trees, of course, act as long–term or inbuilt nutrient pumps, laying down their minerals as leaves and bark on the soil, where fungi and soil crustacea make the leaves into humus.

8.19
SOILS IN HOUSE FOUNDATIONS

Soils cause perhaps 60–80% of all house cracks and insurance claims for faulty construction and "tree damage". About 20% of the soils we build on will subside or heave depending on water content. Specifically, black cracking clay, surface clays, and red–brown clay loams are subject to swelling and shrinking. Solid stone and brick houses are most subject to structural failure, with wood–frame and veneer less so.

Over–irrigation of gardens, causing the water table to rise, is a primary cause of soil swelling. The removal of trees assists this process, as do paved areas, and burst or leaking sewage and water pipes. Some notorious white or yellow clays collapse as dam walls when wetted. It is as well to consult your local soil expert for large constructions as trials can be expensive.

While the effects are most noticed to 2 m deep, probes to 10 m deep need to be monitored for groundwater levels. Soils subside and shrink with excessive drying (too many trees too near the house) and swell and heave with excessive watering and no trees. Adelaide (Australia) is an area where most damaged houses are on blacksoil clays, but several other areas also suffer these effects, and in some, large buildings need to be built on foundations capping deep piles (to

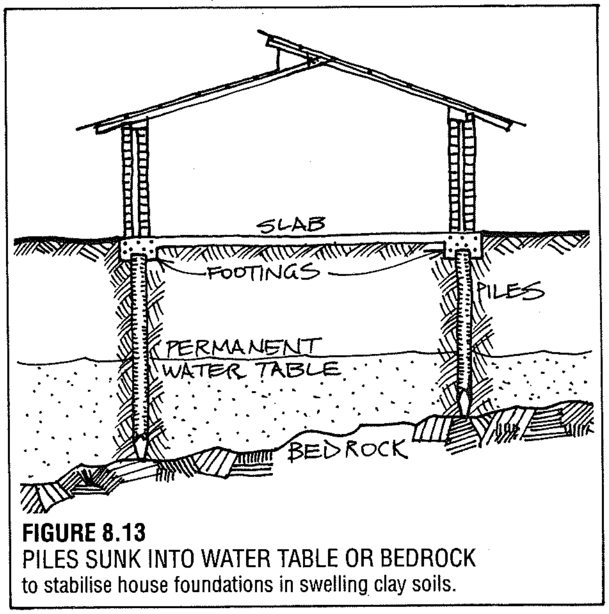


FIGURE 8.13
PILES SUNK INTO WATER TABLE OR BEDROCK
to stabilise house foundations in swelling clay soils.

20 m) sunk to the bedrock or deep into the permanent water table (**Figure 8.13**).

Most Australian native trees have an efficient water removal via roots, so that eucalypts remove 2–3 times the water of pines or pasture (to 10 m radius). Generally, householders should keep large trees at least one half the mature height from the house when building in high clay-fraction soils; sands and sand-loams are usually stable, as are rotten or fractured rock and sandstones.

8.20
LIFE IN EARTH

Before we ever learned to cut open the soil, it was thoroughly dug, aerated, and overturned by multitudes of industrious burrowers. The unploughed meadows of Europe and America are as soft as a great mattress, and are well aerated due to the moles, gophers, worms, prairie dogs, rodents, and larvae eternally at work below ground, even under the snow. Termites, ants, and crustaceans all do their part. The results are obvious from the good soils and great productivity of unploughed ground which has not been compacted by hooves or machines.

Termites and ants are the earthworms of the deserts and drylands, carrying tons of organic material to underground compost piles, in some of which they may grow fungi to feed their colony. The upthrown earth, whether from ants or moles, forms a specific niche for annuals to seed on, and wind-blown pioneer trees to occupy. If birds are the seedscatterers of the forest, burrowers are the gardeners.

Underground and beneficial fungal spores eaten by squirrels or wallaby and activated by their digestive enzymes break hibernation to occupy new ground and help the new roots of acorns and eucalypts to convert soil minerals and liquids to food. Gophers and moles industriously carry roots and bulbs to secret stores and sometimes forget their hoards, so that sunroot, gladioli, daffodils and hyacinths spring up in unexpected places above ground. This is how comfrey and sunroot spread, despite their lack of viable seed. They depend not on bees, but on moles and gophers for their increase. Foxes eat fruits, and defecate on gopher mounds, which are the dug-over areas for new trees.

Wombats may tunnel, overturn, and even topple many hectares of trees, leaving a richly-manured, open, and fertile bed for new forest evolutions. Rabbits industriously garden thistles, and their tunnels give shelter to possum, squirrels, bandicoots, snakes, and frogs.

Worms and crustaceans, in their damp and sometimes semi-liquid burrows, move up and down like a billion pump plungers, sucking in and expelling air (and thus nitrogen) to roots, and in effect giving the soil its daily breath. Many creatures mix up special mudbrick soils with body secretions, and from

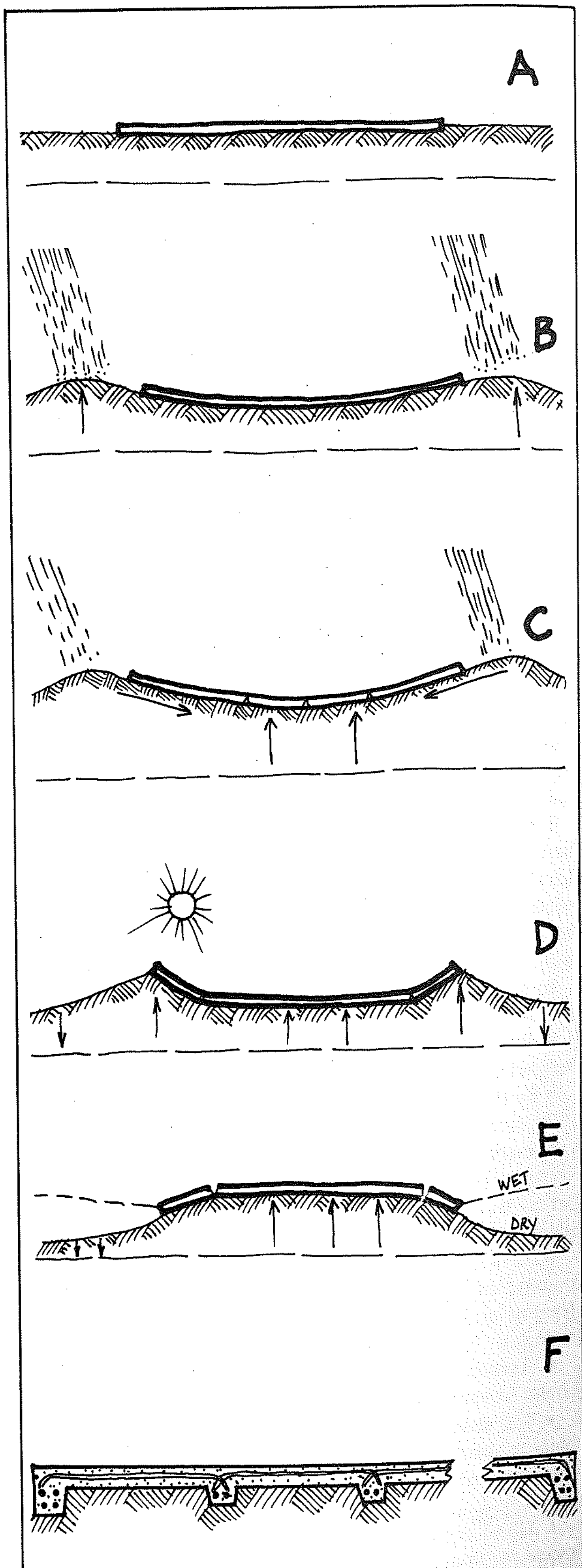


FIGURE 8.14
A–E HOW A MOUND DEVELOPS UNDER A HOUSE
F Slab plus beam construction helps stability.

swallows to termites create homes from stabilised soils. Seeds and spores are buried, excavated, hidden, activated, and forgotten by burrowers, and recycled to life or humus as chance and nature dictate.

Roots die seasonally, invade and retreat, and leave minute or massive tunnels for animals, fungi, and new roots to follow. I once tried to dig a parsnip out of newly drained swamp ground, following it along an old root trace, but gave up after 2 m. I did persist in following a 4 cm long engaeid "land crab" or earth lobster to 2 m down and 2 m along, and have often dug out rabbit and mouse burrows to find their nests, mating circuses, air vents, nursing chambers, disposal chutes, and escape hatches. Many old gopher burrows are filled with plant remains and faecal wastes.

A few dedicated souls in the history of science, from Sir Albert Howard to modern ecologists, try to excavate and discover something of roots, but as a simple bluegum (*Eucalyptus globulus*) can easily embrace an underground 1.5 ha, a forest is so complex and even intergrafted below ground that the canopy seems simple. Many desert plants lead a long and sturdy underground life while thin, straggly, and ephemeral in air. Some insects, like swift moths (*Hepialidae*) spend 7–8 years underground as large bardi grubs (a succulent treat for Australian diggers), with only a few days of nocturnal foodless life in air, mating and laying eggs before disappearing again to the root sheaths and soil, as their near cousins the ghost moths and witchetty grubs do in aerial stems. The bardi grubs, too, open thousands of shafts to the air, and cycle tons of nutrient underground, as do their relatives in air and sunlight. Their predators follow these hoarders and burrowers below the soil, and hunt them in darkness and secrecy.

The implications for designers are that many of these effects may be put to use, or their uses appreciated; it is as valid to plant an *Acacia* for the considerable by-product of swift moth or ghost moth larvae as it is plant a mulberry for silkworms, and to use moles instead of mole ploughs, or gophers as daffodil gardeners (unpaid). Even on shores and the bottom of lakes and seas, the burrowers work to carry nutrients below to roots and to bring up fresh minerals for decomposition, while assisting the flux of liquids and gases across the surfaces of mud media.

Roots have their own PENETRATIONS (depth), PATTERNS or spread, SCHEDULES, seasonal MIGRATIONS to or from the surface, and equivalents of deciduous drop or bark decortication, dying off and sloughing off root branches and bark. It follows that there is a topography of plants underground that parallels that of plants in air. There are also basic differences, in that special storages or fire–resistant organs found underground as ligno–tubers, tubers, bulbs, and rhizomes are very common.

Some species secrete phenols or creosoles to inhibit other plants (bracken, tamarisk, *Juglandaceae*, *Brassicas*); others encapsulate or surround hapless competitors (*Eucalyptus*, willows, tamarisks). Some trap nematodes and other would–be predators, or poison them out (marigolds, fungi, *Crotalaria*). While agricultural crops exploit from 0.6–4 m (2–12 feet) below the earth, some trees may penetrate to 50 m (164 feet) in deep desert sands. Around the roots of dune trees, calcium and other minerals are deposited as stone–like secretions by root–associated fungi and bacteria. Root space sharing is also scheduled, so that spring bulbs have fed, flowered, and died before the tree roots begin their upward thrust for nutrients and water. Tap–rooted late starters such as thistles and comfrey reach deep for late summer moisture, while a very few plants and fungi take advantage of the autumn rains for flowering and dispersal.

Where there is no season of cold death, as in the low latitudes, aerial roots may develop, or strangler figs send down roots from high in the crotches of other trees to the earth, there to build great buttresses as they strangle their host tree in a root well.

For designers, the diversity of roots in soil can be used as effectively as the diversity of crowns and canopies. Unstable slopes are pegged with the great root "tree nails" of chestnut and pine, oak and walnut. Even after a hundred years, the steep slopes of this island (Tasmania) are only just starting to collapse as the roots of the cleared forests rot, and could still be saved by pines, *Acacias*, or chestnuts. Bamboo not only holds landslides, but for light structures provides an earthquake–proof mattress of roots. The root mats of swamp vegetation save bulldozers from watery graves, and the fibrous web of the prairie defeats the wind.

GEOLOGY AND LIFE FORMS

Many rocks and strata on earth arise from the actions of living organisms. Whether it is the nodules of manganese in oceanic depths, deposits of diatomaceous earth, coal, or limestone, or opals and amber, all were once the products of living organisms. Much of the strata we see, except much–changed granitic and volcanic deposits, were formed from or modified by life. All soils are life–created, as are the corals and coral sands of many oceanic islands.

Life is also busy transporting and overturning the soils of earth, the stones, and the minerals. The miles–long drifts of sea kelp that float along our coasts may carry hundreds of tons of volcanic boulders held in their roots. I have followed these streams of life over 300 km, and seen them strand on granite beaches, throwing their boulders up on a 9,000 year old pile of basalt, all the hundreds of tons of which were carried there by kelp. Round stones are dredged from great depths in the mid–Atlantic; this does not mean that they were formed there, but more likely that drift kelp carried them there in their roots. Before they fly to Japan and Alaska, some millions of petrels (*Puffinus tenuirostris*) annually fill their crop with Tasmanian pebbles, seeds, and charcoal, which will be voided somewhere in the Pacific.

Life moderates every erosion process, every river basin, every cliff and rock fall. It shapes and reshapes earth in a thousand ways.

The hydraulic weight of great forests, such as were once in the Americas, would have exceeded any water catchment weight we can now afford to build, and dispersed it over a greater area. This greatly moderates climate, and with it geological processes. It is possible, in Iran, Greece, North Africa, USA, Mexico, Pakistan, and Australia to see how, in our short history of life destruction, we have brought the hard bones of the earth to the surface by stripping the life skin from it for ephemeral uses. We can, if we persist, create a moon–landscape of the earth. So poor goatherds wander where the lake–forests stood and the forest deities were worshipped. The religions of resignation and fanaticism follow those of the nature gods, and man–built temples replace trees and tree spirits.

8.21
THE RESPIRATION OF EARTH

All of the skin and organs of the earth breathe; it is a regular respiration. The "diaphragm" or energy for this may be provided by the moon tides in water, earth, or air. Locally, the filling up of soil by rainwater forces an exhalation of air; the drying–out an inhalation. Fast winds disturb boundary layers, create low pressure and soil exhalation; slow winds and high pressures force inhalation. Millions of earth animals open breathing tubes, and arrange them (for their own sake) to force an exchange between the atmosphere and the waters, the soils, or sea–sands in which they live. Water is as much breathed as air.

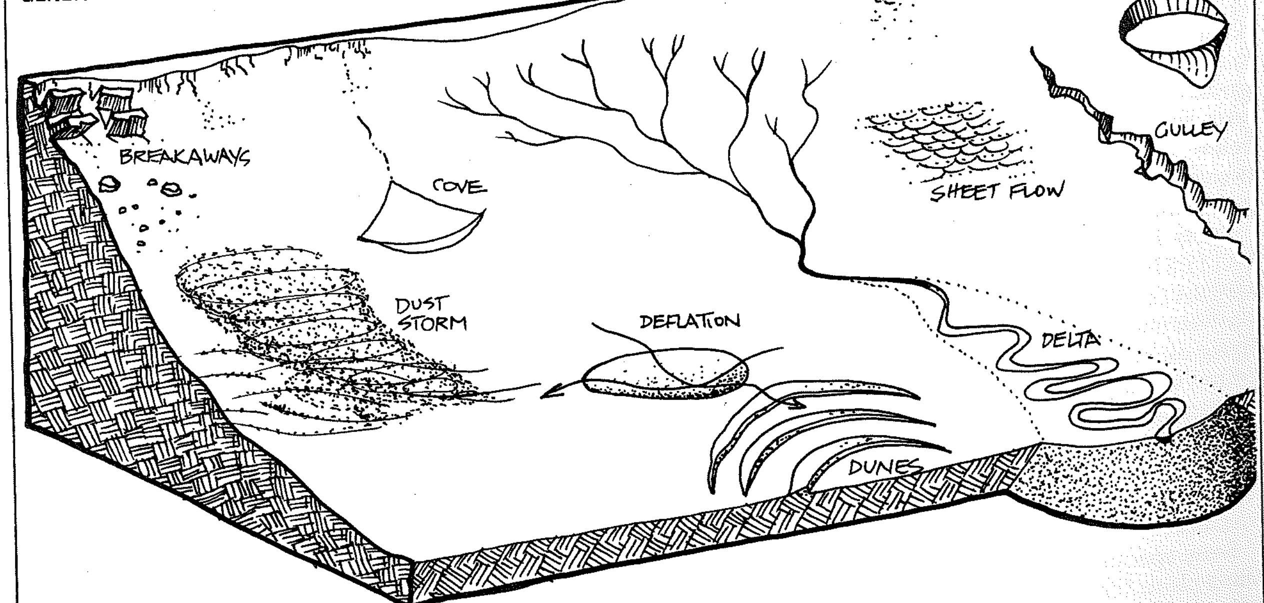
Deeper respirations come from deeper flows and fissures, and radon gas or methane seeps out from the earth. When the earth itself expands, great flows inward and outward must occur through the multitudinous fissures that open up in rigid sediments. This earth respiration transports and transforms fluids and their associated loads, solutes, states, and ionic potential from earth to atmosphere to ocean, setting up the potentials that create thunderstorms or hurricanes. We are of this same respiration. The burrows of spiders, gophers, and worms are to the soil what the alveoli of our lungs are to our body. We can assist this essential respiration by assisting life and natural processes in soils.

> If you kill off the prairie dogs, there will be no one to cry for rain.
> (Navajo warning)

Amused scientists, knowing that there was no conceivable relationship between prairie dogs and rain, recommended the extermination of all burrowing animals in some desert areas planted to rangelands in the 1950's "... in order to protect the roots of the sparse desert grasses. Today the area (not far from Chilchinbito, Arizona) has become a virtual wasteland." Fierce run–off, soil compaction, and lack of fresh seedbed have carried the grasses away (Barre Toelken, in *Indian Science Quest '78*, Sept/Oct).

Using prairie dog burrows as water sinks, and causing water run–off to flood down them, thus germinating stored underground seed, had the opposite effect on the Page ranch, now a dryland

FIGURE 8.15
GENERAL SOIL EROSION PROCESSES IN LANDSCAPES



rehabilitation exhibit of the University of Arizona. Here, prairie dogs and a new and thriving patch of permanent bunch grasses thrive in an area where overgrazing, ploughing, or soil compaction has ruined other grasslands.

> Water under the ground has much to do with
> rain clouds.
> If you take the water from under the ground,
> land will dry up.
> (Hopi elder in *Tellus*, Fall '81)

At Black Mesa, near the Four Corners area of the Hopi Indians (USA), a scientist studying thunderstorm occurrence (using computer analysis) noticed an unusual number of storms occurred in that area. She was told by the Hopi of the area where the earth breathed, emitting air as the moon affected the groundwater tides. This air proved to be heavily charged with negative ions, which may have initiated the thunderstorms and consequent rain.

Of the breathing of the earth, there has been little study, although it was regarded as a known phenomena to tribespeople. The earth must breathe, by at least these processes:

- The movement of burrowers in their tunnels;
- The movement of groundwater by tides or replenishment of aquifers (often seen in wells, especially near coasts and lakes); and
- The evaporation of moisture from soil surfaces by the sun.

8.22

DESIGNERS' CHECKLIST

1. It is a *primary* design strategy to prevent topsoil losses and to repair and rehabilitate areas of damaged and compacted soils.
2. Permanent crop, soil bunds, terraces, and low–tillage systems all reduce soil and mineral nutrient loss.
3. Soil rehabilitation and pioneer green crop should precede other plant system establishment.
4. Adequate soil tests, plus test strips of crop examined for deficiency or excess symptoms, leaf analysis, and livestock health should be assessed to guide soil treatments.
5. If soil types can be specified, fencing, cropping, and treatment should coincide with these specific soil assemblies, and specific crops for such type researched.
6. Soil life processes need to be encouraged by provision for green crop, humus, mulch, and the root associates (mycorrhiza) of plants. A useful earthworm may need to be introduced.
7. Drainage, hence pH and soil water capacity, need specific treatment or assessment, and will largely determine crop and tree types.
8. Minimal use of large livestock and heavy machinery is to be recommended on easily–compacted soils, as is burning and clearing.
9. Use pigeon and animal manure where major elements are scarce, as in third world areas (also use of greywater and sewage, or wastes).

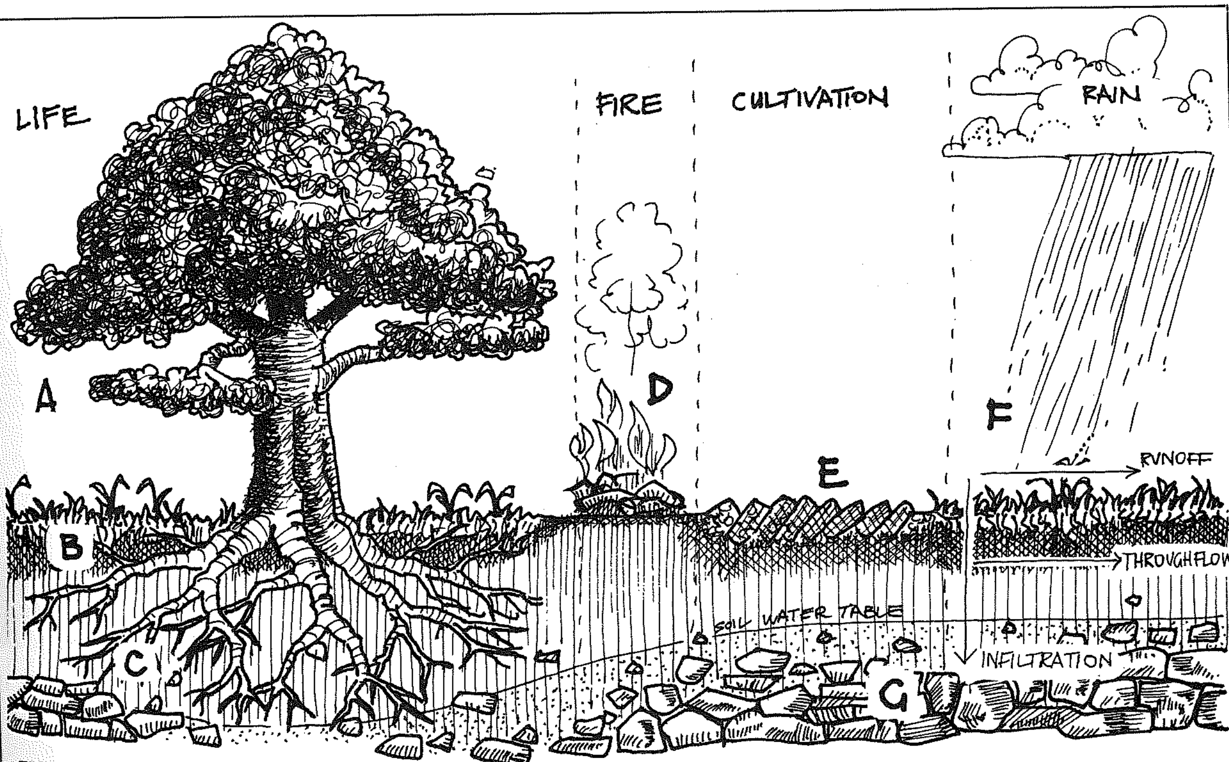


FIGURE 8.16
Soil creation (A–C) and factors aiding erosion and mineral loss (D–F).

10. Before draining waterlogged soils, recommend crops to suit this condition. Never drain wildlife habitats, fens, or bogs which are species–rich.

11. Choose the right soil–shaping or earthworks to suit crop, drainage, and salt threat.

12. Using an auger, check soils for house foundations. Using a (wetted) soak pit, time the absorption of greywater for sewage disposal at house sites.

13. Preserve natural (poor) sites for their special species assemblies; pay most attention to human nutrition in home gardens, and select species to cope with poor soil conditions on the broadscale.

14. Fertilise plants using foliar sprays containing small amounts of the key elements, or pellet seeds with the key elements which are deficient locally. Pelleted seed and foliar sprays are economical ways to add nutrients to plants.

8.23
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