YOUR GARDEN SOIL

HOW TO MAKE THE MOST OF IT

Contents

YOUR GARDEN SOIL

HOW TO MAKE THE MOST OF IT

Chapter 1

From the Ground Up—A General View of Soils

WITHOUT soils, no life could exist on earth. The lowly bacterial cell and the massive pachyderm both owe their being to this basic stuff of life. A bird in flight, a mole burrowing beneath your lawn, borers eating blindly into the heart of a great oak—all are linked by their common dependency on the elements of existence they draw from the soil.

Of all the earth's living creatures, man alone manipulates and modifies the land to better suit his ends. Not satisfied with soil as he finds it, he tears its surface, incorporates organic and mineral materials and alters age-old structures. He often keys his actions to two false but widely held ideas: 1, that soils are simply clay and decaying vegetable matter—a mechanical support for plants—and 2, that the easy-digging quality of the soil means more than its chemical-biological quality. The error of this over-all viewpoint was thrown into sharp focus not so many years ago by the controversy concerning the use of synthetic chemical soil conditioners. These products often made soil easier to till but with no resulting improvement in quality of plant growth. The "organocultists," those who believe only in organic gardening, have much to say about all this. Their ideas are aired in a later chapter.

TIPS ON TYPES

Soil *type* is important. Type is determined largely by texture, a word often used in the wrong sense. It means simply particle size, such as fine sand, gravel, silt, clay, and so on.

Particle sizes in soils range something like this (mm = millimeter; 25 millimeters equal one inch):

Mineral elements:	Clay	.002 mm or smaller
	Silt	.002 mm to .05 mm
	Fine sand	.05 mm to .25 mm
	Sand	.25 mm to 1.0 mm
	Gravel	1.0 mm to 32 mm
	Stones	over 32 mm

Organic matter in soils may range in size from as large as entire plants that have been dug under to as small as humus particles so fine that they form colloidal solutions. (In a colloidal solution the minute particles do not settle out, but float indefinitely.)

Based on the preceding information, here is a soil classification according to particle size (comments are explained throughout the book):

Stony loams	Soils containing more than 50 per cent stones over 1 inch in diameter. If remainder is sufficiently fertile, this soil type may have gardening value, although it will be hard to work.
Gravels	Soils with over 50 per cent gravel and much sand. Practically no garden value.
Sands	Soils with more than 75 per cent sand. Low garden value.
Fine sandy loams	Soils with 50 to 75 per cent fine sand mixed with much silt and some clay. Fairly good garden soils.
Sandy loams	Soils with 50 to 75 per cent sand and much silt, some clay. Among the better light garden soils.

Loams	Soils with 35 to 50 per cent sand mixed with much silt and some clay. Most of the better garden soils fall in this class.
Silt loams	Soils with more than 50 per cent silt and less than 15 per cent clay. Are too "tight" to be good soils without some modification.
Clay loams	Soils with 15 to 25 per cent clay, much silt and little sand. Usually are good garden soils if not worked when wet.
Clays	Soils with more than 25 per cent clay, usually with much silt. Can be good if handled properly.
Mucks	Soils with 15 to 25 per cent partially decomposed organic matter with much clay and silt. Good for certain crops, but modification is usually needed for general garden use.
Peaty loams	Soils with 15 to 35 per cent organic matter mixed with much sand and some silt and clay. If acid, are good for broadleaved evergreens.
Peats	Soils with 35 per cent or more organic matter, mixed with some sand, silt and clay. Need more mineral matter to be suitable for garden use.

Soil type has to do with mechanical makeup of soil. Type does not give much clue to the value of a given soil for growing plants. By habit we associate loams with rich soils, yet certain loams may be poorer than some clay or sandy soils.

Soil type concerns you in three vital ways. First, many recommendations for applying fertilizer, for treatments to adjust pH (acidity-alkalinity) , and for other applications of chemical substances to soil give different rates for clay, sand, and other types. Second, a knowledge of texture-types gives some clue as to how well a soil will hold fertility. (Fall feeding is possible for a lawn on clay loam soil, for example, where this would be unsuccessful on a light sandy loam.) Third, knowing your soil type will often tell you in advance whether it will drain well or will puddle and wash under heavy rains.

These three points are chiefly important now, at the beginning of our discussion on converting a native soil into Gardener's Loam. They will lose their importance once we have incorporated soil amendments and extra organic matter into the soil, for then original type will be so modified that it will have to be revaluated in light of its new characteristics.

An accurate test of texture and type requires an involved laboratory procedure. A rough check, accurate enough for gardening purposes, can be made by the soil wash test, as described in the chapter on testing (Chapter Three).

A CULTURE OF MICROORGANISMS

"I certainly don't want to add germs to my soil," exclaimed one gardener when I tried to persuade him to treat peas and beans with a nitrogen-bacteria culture. He would have been astounded if he could have seen the billions upon billions of microorganisms he harbored in his relatively poor soil. He just could not accept the idea that soil is a culture of such organisms, just as much as it is a mechanical support for plant roots.

Few gardeners deliberately set out to increase the biological life of soil, yet this is the main purpose behind every addition of organic matter. (Long before he knew why, man observed that plants grew best around places where rotting plants and manure had accumulated.) When we treat soils so that beneficial bacteria and useful fungi are stimulated, plants grow better and returns for time, effort and money used are increased. Much of this benefit concerns plants that prefer near-alkaline soils. Acid-soil species, however, are also benefited by the stimulation of useful fungi. A good example of this are the mycorrhizae—specialized fungi that form a feltlike covering on roots of acid soil plants and help them use ammonia as a source of nitrogen. Without these fungi operating in the soil, rhododendrons, azaleas, blueberries, hollies and many other ericaceous plants grow poorly, if at all. When we provide conditions that favor rapid increase and continued growth of mycorrhizae, these plants thrive. If, however, plants are set in heavy clay or planted so deeply that air does not move freely around the roots; or when soil moisture fluctuates widely (sometimes wet and sometimes dry), or when a protective mulch is missing, both plant and fungi suffer. I have several times made the statement, "To a considerable extent, the culture of acid-soil plants is the culture of mycorrhizae. Do what is good for the fungi and the plants will thrive." The same might be said for plants that thrive in less acid soils as well.

The function of fungi and bacteria is to process and make available food elements too complex for higher plants to absorb. This vital process will be explained later in detail.

Soil organisms are important in another way: as they live and die they absorb, conserve and then gradually release soluble nutrients that might otherwise be lost; thus they increase fertilizer utilization many times over.

SOIL AS A CHEMICAL LABORATORY

Although each phase of soil already mentioned is vital, we cannot lose sight of soil as a chemical-mineral material. We must also remember that all nutrients are absorbed either as relatively simple chemical compounds or in nearly elemental form. Plants are unable to directly use complex proteins, animal wastes or similar products of growth. Decay must first release stored foods in simpler forms, then these are taken up by roots.

For this reason, we must study the chemical side of soils, to understand why conversion of organic matter to simpler products is a vital phase of soil. Chemical, as opposed to organic, fertilizers have become the subject of much controversy. Later on (in Chapter Five) we will explore the relative merits of these fertilizers.

All nutrients used by plants *must* be in liquid form, since plants have no teeth or specialized organs for grinding solid foods and lack any semblance of a digestive system. For this reason, water is another vital factor in assuring maximum growth in any soil. About 98 per cent of all plant tissue is the product of air and water, with only 2 per cent contributed by soil elements.

In normal soils, plant growth is probably limited more by inadequate water supplies than by lack of any other element. A program of soil management is incomplete if it ignores water and air as vital factors in, and sources of, nutrition.

MANY ROUTES TO BETTER SOIL

In this short resume of a few of the properties of soil, we have discussed several which are vital to plant growth, yet plants in the wild have survived for centuries without any human attention to these properties. Why then bother to change them? Is not natural growth enough to meet our needs?

The answer is a qualified "No." If native soils are rich, well-drained and abundantly watered by rainfall, obviously any crop adapted to the region, whether for food or ornamental purposes, will thrive. Some improvement in plant growth of value to the gardener might result from adjustment of one or more of the soil factors just discussed, but hardly enough to repay any extra effort.

The catch is that very few of us are fortunate enough to have ideal conditions. I have checked soil surveys of five leading agricultural states to see how much "ideal" soil exists. In these surveys, top quality land was graded as #1, and the rest graded down to #10. In no state could I find as much as 10 per cent of the land that would grade as #1. Thus, even if you happen to live in one of these top agricultural states, the chances are nine to one against your having soil which does not need attention.

CHAPTER DIGEST

Soil is the most fascinating element in your garden, and it is also, for practical purposes, an easy-to-understand element. Types of soil, organic and mineral content, and the beneficial activity of soil fungi and bacteria, all bear heavily on your success with plants. With a minimum of knowledge you can make this marvelous material—soil—your greatest gardening ally.

Chapter 2

Make the pH Work For You

ONE of the principal influences for good or bad in soil is its pH. This used to be the province of scientists and chemistry students, but over the past few years it has become part of the home gardener's everyday world. In many, many cases, pH is the key to proper plant growth, and a pH reading can tell you much about what is going on beneath the surface of your garden.

Soil pH can be a highly technical subject, but for us it need not be. Actually the pH scale is just as easy to work with as the thermometer scale. You don't have to know thermodynamics, heat transfer and other aspects of temperature to understand what happens to your plants when thermometer readings drop to or below 32° Fahrenheit. Similarly, without knowing a thing about hydrogen and hydroxyl ions, logarithm exponents or other technical details of the pH theory, you can make practical use of soil pH elements that your plants (and the soil organisms) need.

DIRECT AND INDIRECT

Effects of pH are both direct and indirect. Direct effects, while not numerous, can be critical. In the case of a soil that is too acid or too alkaline, there can be (1) toxic effects on the plants themselves, and (2) an unfavorable balance between acid and alkaline elements needed by plants.

Indirectly the pH can have an effect on one or more of the following:

(1) Availability of essential elements
(2) Activity of soil microorganisms

(3) Solubility and potency of toxic elements
(4) Prevalence of plant diseases
(5) Competitive ability of different plant species
(6) Physical condition of the soil (when lime is used to raise thepH)

The pH scale is a measure of balance between acidity and alkalinity of soil solutions. The scale is simplicity itself, being a series of numbers starting at 0.0, the most acid, and running in tenths up to 14.0, the most alkaline. The neutral soil reaction on the scale is 7.0, the mid-point where acid and alkaline elements are in balance. (Soil reaction refers to the degree of acidity.) Gardeners do not use the entire pH scale, since reactions from 4.0 to 9.0 are just about the limits for plant growth.

Each full step or unit up or down on the scale (say from 6.0 to 7.0 or 7.5 to 6.5) represents a tenfold increase or decrease in the degree of soil acidity. For example, a soil solution with a pH of 6.0 is ten times more acid than one with a pH of 7.0.

SOILS CLASSED BY pH

Years ago, Dr. Edgar T. Wherry devised a classification of soils by degrees of acidity; it is still useful but should be qualified by the fact that many plants spill over into two or more classifications while some are relatively sensitive to pH. Under his system, soils are classified as follows:

Superacid: Bogs, largely of sphagnum origin, with a pH range of 3.0 to 4.0. Only a few plants thrive under these superacid conditions. Because bacteria and fungi cannot function at this low reading, organic matter breaks down slowly or not at all. (It is interesting to see that two plants which do well in superacid soils—pitcher plants and sundews—do not rely upon soil for nitrogen, but are carnivorous.)

Mediacid: Bogs of sedge and sphagnum where no run-off from lime-bearing soils drains in. The pH is from 4.0 to 5.0. Broad-leaved evergreens thrive on moist mediacid soils, while hemlock, spruce and oaks grow on somewhat drier areas.

Subacid: Older gardens and fields from which lime has been all but exhausted, resulting in a pH of 5.0 to 6.0. Also includes old upland woods and some swamps.

Minimacid: Gardens and fields which are limed from time to time; woods on soils over limestone; old untilled grasslands or soils under oaks. The pH ranges from 6.0 to 7.0.

Minimalkaline [including Neutral]: Marshes and lowlands into which water drains from lime-rich soils. Contain debris from limestone ledges and cliffs, and leaf mold from hardwood forests except, under most instances, from oaks. The pH is from 7.0 to 8.0.

To the above classification we might add a group for gardeners who live in the Great Plains area where rainfall is too light to leach out alkalizing chemicals, resulting in alkali- and salt-sick soils typical of such regions with a pH of from 8.0 to 9.0.

TWO IN ONE

Dr. Wherry linked minimacid and minimalkaline soils into a broader class he called Circumneutral. This may be a somewhat bookish word, but it does convey the impression of a wide range of plants that will thrive in a wide range of soil reactions, from 6.0 to 8.0. It has been my experience, however, that even these tolerant plants—including most annuals, perennials and so on—respond better to a narrower range of pH, say from 6.0 to 7.3 or from 6.0 to 6.9. Under these less alkaline conditions the plants[7] leaf color is better, even though there is no other sign that soil pH has affected growth.

My gardening preference is for plants classed as circumneutral at a pH range of 6.0 to 6.9. Within this range all the food elements they need are available in highest concentration except perhaps for iron, zinc and copper, which are, however, present in large enough amounts for normal growth.

Organic matter, a vital soil ingredient that we will discuss later, has an important effect on pH. When present in the soil in generous amounts it "buffers" the bad effects either of a too acid or a too alkaline soil. For this reason, plants growing in a soil high in organic matter will often do well even though the pH reading is nearly a point either way from the ideal range. As will be seen by consulting the plant pH preference list which appears in the Appendix, most plants commonly grown in gardens do best within a pH range of 6.0 to 6.9. Only those which require an acid soil (rhododendrons and blueberries, to name two, usually called ericaceous plants) require a lower pH.

Here, then, is a key to better plant growth—keep the soil pH between 6.0 and 6.9 and keep up the organic content

THEN AND NOW

Grandfather knew nothing about the pH scale. Even if the theory had been invented in his day he probably would have called it "book rubbish." Nevertheless, he knew enough about soil reaction to spread load after load of marl or ground limestone on his fields every third or fourth year. He did this to "make the soil sweet and keep the land up," as he phrased it. He knew that when the lime began to "dissolve" his crops grew better and he made more money. Too, the soil would be in better "tilth" and would turn more easily under the plow.

In this simple but important chore he was repeating what generations of farmers since Roman days had done before him—overcoming a too-acid soil with lime. Although ignorant of chemistry, he knew a soil was "sour" if sorrel grew well, or "sweet" if clover and alfalfa thrived. Sometimes, if in doubt about the time to lime, he would touch a grain or two of soil to his tongue. If it had a soapy taste he knew it had some lime in it but if it tasted acid or sour he laid plans to supply the missing element. Plant growth improvements seemed so directly connected with these applications that he thought of limestone as "rock manure," supplying something the plants had to have. Today we know that while lime does supply calcium, usually the indirect effects are much more important than the direct. This in no way detracts from the soundness of grandfather's methods—he got results.

You need know little more than he did in order to use pH correctly. True, you have the help of modern soil testing equipment much more accurate than the human tongue, and you can regulate the actual pH range more accurately. But without any scientific background you can correctly apply lime and fertilizer on acid soils, or if your soil is too alkaline you can apply sulfur to bring down thepH.

LIME AND SULFUR ALTER pH

As mentioned, when growing all but a limited number of plants (acid-loving species like blueberries, mountain laurel [kalmia], hollies, camellias, azaleas and rhododendrons), you should strive for a soil reaction somewhere between 6.0 and 6.9. Ordinarily, a reading of 7.3 is as high as your garden soil should be allowed to go if you are growing the usual mixture of annuals, perennials, vegetables and shrubs. For many plants, even this is a trifle high. Growth would be better if sulfur were used to lower the reading.

It is difficult to make exact recommendations for amounts of chemicals needed to raise or lower soil pH. Light soils require lesser and heavy soils need greater quantities of acidifying or alkalizing agents. A soil high in organic matter has a different requirement than one low in organics. If the organic matter in the soil has been reduced to humus, the "buffering" effect of the humus usually increases the amount of pH alteration material needed.

The only sensible way to solve the problem is to treat the soil and recheck the pH reading after two weeks, after a month, and again after two months. If not enough material was applied, simply add more. If too much, there is no harm in using sulfur to undo the effects of limestone, and vice-versa.

Here are some suggested amounts:

To raise the pH of light sandy loams one full point (i.e., from 5.5 to 6.5) add 35 pounds of ground limestone to 1,000 square feet. On a medium loam soil, apply 50 pounds, and on a heavy clay loam, 70 pounds. (Either agricultural limestone or the fine chips used for top-dressing driveways can be used.)

To lower the pH of light sandy loams one full point (i.e., from pH 6.0 to 5.0) add 10 pounds of dusting sulfur per 1,000 square feet. In medium loam soil, add 15 pounds, and to heavy clay loam, 20 pounds. (Ordinarily dusting sulfur is perfectly satisfactory; no need to pay a premium for special grades.)

Within the 6.0 to 6.9 range, all foods needed by the majority of shrubs, annuals, perennials and other "average" garden plants are available in the soil in soluble form, provided the foods are present in the first place. Bacteria thrive and do their vital work better in this pH range, and certain potential poisons, such as aluminum, are locked up so they cannot injure plant roots.

Pay particular attention to the above phrase, "provided the foods are present in the first place." No matter how pH is juggled up or down, it cannot make available any food element that is not present. For example, plants may show by certain signs that they are not taking up iron from the soil. If the pH is high, we might suspect that iron is present but locked up in insoluble form. If, however, plants still show a deficiency of iron after sulfur has been applied to lower the pH, then we know that iron is lacking and must be supplied in a form plants can absorb.

Because plants tend to remove calcium from the soil as they grow, which in turn lowers pH, lime is closely tied in with our use of the pH theory. To a considerable degree, proper lime application (assuming supplies of plant nutrients are ample) becomes the key to our success with garden soils. This does not mean that the indiscriminate use of lime year after year is the right way to run a garden. Too much alkalinity can do as much harm as too little. This is why no "rule of thumb" can be set up that will work all the time in every garden. The only safe guide is an actual test of soil reaction.

MAKING THE pH TEST

There are several methods of making a pH test. The most accurate, and one that will probably be used if you send soil samples to your state agricultural experiment station, is an electrical "bridge" which checks the reaction by electrical resistance. This is an expensive piece of apparatus and one that few amateur gardeners are likely to buy.

While this device gives extremely true pH readings, I strongly recommend that gardeners use home test kits despite the probability of less accurate results. There are a number of reasons why. First, since most stations charge for each sample submitted, the economy-minded gardener's usual practice is to mix soil from several sites into one sample and submit it for an "average" test. If the soil throughout the garden is uniform, this average test method is satisfactory.

Such a situation, however, is quite unusual. For example, black dirt used as topdressing over backfill around most speculative (development) houses may come from piles of earth scraped from half a dozen different sites.

My own vegetable garden, while on land graded nearly a hundred years ago, is an example of how much the soil in one plot can vary. In one area it lies over an old creek bed that was filled-in in 1868 to make a level building plot. Since this was before bulldozer days, I can just imagine an old-fashioned horse-drawn scoop cutting down the hill on which the house was built, partially filling the creek with this earth. In another spot I find prairie soil of a different character. In one corner of the plot, tons of coal ashes were used in a mixture with some black soil and manure from a barn that once occupied the site.

All this soil history has been revealed gradually. Over a period of years I have double-dug the entire garden, uncovering everything from old barn footings to a buggy dashboard and an 1850 whiskey bottle. Incidentally, I unearthed a midden of undecayed chicken bones and rabbit skulls, which merely confirmed for me again the fact that bone (a good source of phosphate) resists decay for decades.

In this one garden, a small section filled with old eroded woods soil had an acid pH of 5.8, while the other end of the garden, where ashes predominated, tested 7.8. Obviously, if I had mixed these two to get an "average" sample I would have received a report of no value to me in working with either the acid or alkaline soils.

If you have your own test kit, however, various sections in your garden can be tested and treated individually. Even though such kits cannot be expected to be much more accurate than within two or three fractions of a point, they are much better in practical application than the more accurate electrical bridge tests of a single "average" sample.

BEST KIT FOR YOU

I recommend kits which use a special liquid that, when dropped onto a crumb of soil, turns color according to the degree of acidity or alkalinity of the sample. This can then be compared directly with a color chart to get the reading. Some kits of this type supply a small china dish to hold the sample while others use glass tubes. A low cost unit which uses strips of wax paper is perfectly satisfactory once you learn to juggle the folded paper and read it against the chart.

Be sure to buy a unit that gives readings in direct pH figures, not in some mythical A, B, C system or in Roman numerals. Kits of the latter type are often sold cheaply or given away, but usually have to be used with a special product. Many of these products incorporate undesirable chemicals (such as aluminum sulfate used for acidifying) which you want to avoid.

Your first step in making a pH test is to get a uniform sample of the plot being tested. Don't use surface soil (roots rarely grow there) but dig down six inches. Avoid large lumps of organic matter unless you have a true organic soil such as peat or muck.

Soil should be moist for several days before you test it. (Drought affects the pH by killing off large numbers of bacteria, releasing organic acids which result in a false reading.) If the sample of soil used is allowed to dry for an hour or so in a shaded spot, it will give a clearer reading when the liquid is run through.

OVER SIXTY

Do not test cold soil. Cold inactivates bacteria, resulting in a false reading. Wait until soil temperature (not air temperature) has been above 60 degrees for at least two weeks, then test.

In making a test, don't neglect the subsoil, unless you are the lucky owner of a four-foot-deep black prairie loam. We forget that if surface soil is only six to ten inches deep, most roots of many crops will grow through that upper layer and get the majority of their nourishment from the subsoil. In checking soil where deep-rooted trees and shrubs are growing or will be planted, perhaps only subsoil need be considered.

Several years ago I saw a good example of why subsoils should be checked. A friend of mine north of Chicago had some magnificent oaks growing at the foot of a steep hill on his property. Heavy washing rains fell all spring, and suddenly my friend noticed that the oak leaves were beginning to turn yellow. A tree man sprayed them with an iron solution and they turned green for a while but soon reverted to yellow.

Tests of the surface soil around the oaks showed it was fairly high in pH, about 6.0, but low enough so that some iron would stay in solution. When, however, we checked the subsoil, we found it tested 7.5. This we diagnosed as a temporary alkaline condition produced by lime washed out of the upper part of the hill by the heavy rains and carried down the hill, along a gravel layer just under the surface, to the roots of the oaks.

Holes bored around each tree and filled with ferrous ammonium sulfate soon brought about improvement in leaf color and tree growth. Drains to lead rain-wash from above into side channels, away from the oaks, prevented further trouble.

HOW pH AFFECTS NUTRIENTS

Now that you have a pH reading, the next problem is what it tells you. We want to know how pH affects food elements in soil.

Food elements needed by plants may not be available to them even though present in soil. Phosphorus is an excellent example. Vital to all life, it enters into every phase of plant growth, from beginning to end. It is a major ingredient in cell nuclei, and carries over in chromosomes to the succeeding generation. It is essential to photosynthesis, one of the most critical processes in the entire world by which energy is captured from the sun and used to run the organic "motors" of every living cell—that is, to produce food.

Oddly enough, for all its essential nature, phosphorus is not readily available in soils except within a rather narrow pH range. When a pH of 5.0 or lower is reached, phosphorus is chemically trapped by aluminum compounds and converted into highly insoluble, fixed forms which are unavailable to plants. Iron is captured in a similar way.

When pH goes up and calcium is present in generous amounts, phosphorus reacts with it to form other highly insoluble compounds. Superphosphate is commonly applied to the soil to supply phosphorus. If it contains any amount of fluorine (as is sometimes the case), and the soil pH is 7.8 or above, fluorapatite, the most insoluble of all phosphate compounds, is formed.

We need not go into the chemistry and interactions of all elements essential to plant growth; the important fact is that availability of nutrients in soil depends so directly on pH that adjusting this factor is something every gardener should know how to do. All of the mineral elements plants need for growth are available between readings of 6.0 and 6.9. Even above and below this range, the minerals are available to a certain extent, so that if small errors are made in reading the tests, it is not too serious.

Here, then, is a basic principle in managing soils—keep pH between 6.0 and 6.9 for all plants classed as circumneutral and you won't go far wrong. This assumes, of course, that the vital food elements were either in the soil when you tested it, or that you will supply them.

PLANTS WITH DIFFERENT NEEDS

When you examine the list of plants and their soil preferences given in the Appendix, you will see that some of them do best at pH readings below 6.0 while a few are able to tolerate alkalinity above 7.5 to 8.0. Why these exceptions?

Here is one of those mysteries that makes soil such a fascinating study. These plant exceptions need nutrient elements which, according to the pH theory, should not be available at the readings listed for them. The answer is that soil is not a uniform, homogeneous mass, like a great blob of plastic with every molecule made up of identical atoms. Instead, soil is a composite: a great macrocosmos and microcosmos rolled into one. Within the same grain of soil can be found acid and alkaline elements existing side by side, "buffered" from attacking each other by a series of checks and balances that allow them to act according to their individual reactions.

Many soil grains are actually "sandwiches" with an acid core and a layer of alkaline material on either side. In acid soil, not all alkaline elements are neutralized, and vice versa. This is particularly true if the soil contains a good percentage of organic matter, the most powerful "buffer" of all.

Acid-soil plants owe their ability to grow at low pH readings to the fact that their roots can tolerate some free aluminum. At readings below 5.5, aluminum is set free unless it combines with phosphorus. This does not mean that the ability of plants to resist aluminum is unlimited: many growers of camellias, rhododendrons, azaleas and other ericaceous plants keep applying aluminum sulfate to acidify soils only to find that their plants deteriorate. The roots may be blackened and injured to a point where they can no longer take up nutrients.

ACID-SOIL PLANTS USE AMMONIA

The various acid-soil plants do not need their organic foods broken down as completely as do plants that require a more alkaline soil. The forms of bacteria and fungi that break down protein to release nitrogen are sensitive to pH. At readings below 6.0 only forms that break the pH down to ammonia are active. At higher pH readings, other organisms carry the breakdown further to produce nitrate nitrogen which all plants can use.

Acid-soil plants—rhododendrons, camellias, kalmia, blueberries—are able to use ammonia nitrogen because mycorrhizae on their roots do the converting of ammonia into nitrate form. (For a full explanation of the role of mycorrhizae, see Chapter Eight on Microorganisms.) Plants in the circumneutral group, on the other hand, must depend upon soil bacteria to carry out this final nitrogen conversion stage. Since these bacterial forms work best in the soil at a pH of 6.0 or higher, circumneutral plants do not survive in acid soil.

ALKALINE AND ALKALI SOILS

At readings above pH 7.3 to 7.5, there is sharp reduction in the number of species which will grow well. Most of those that do survive are plants with relatively light green foliage, such as alpines and plants from relatively dry areas with bright sunshine. Probably they are able to manufacture their food with less chlorophyll than is needed by plants from areas where sunshine is less intense. For this reason, alpines and others need less of the elements such as iron, copper and manganese that become unavailable in highly alkaline soils.

Another factor involved is organic matter. Since at a high pH it does not break down rapidly, it tends to accumulate. Particularly is this true in less humid climates, where soils with high pH are usually found. The effect of organic matter is to buffer high alkalinity. It absorbs certain food elements so they are still available to plants in spite of high pH. Most alpines will be found growing in pockets where organic matter has been trapped, while on the Great Plains, shrubs like the buffaloberry *(Shepherdia)* grow along water courses where flood waters deposit richer soils.

About the only direct effect of too high a pH is aluminum toxicity. At readings above 8.5, aluminum is released and will seriously injure plant roots (just as it does at pH 5.5). Aluminum is also harmful because it makes phosphorus unavailable to plants. Among the vegetables which are seriously injured by even small amounts of free aluminum are lettuce, onions and beets.

LIME: EFFECTS ON pH AND SOIL CONDITION

Ground limestone is a dual-purpose mineral. We apply it primarily to overcome acidity but, in addition, we receive a bonus in soil conditioning (see Chapter Eleven) that alone is often worth the cost and effort of application. An application of ground limestone can give a heavy clay loam a loose, friable, well-aerated character. Such a soil allows water to penetrate readily without running off, and turns easily under the plow.

This change in condition is due to an electrical-chemical-physical reaction known as flocculation. In this reaction, each lime particle acts as an acid radical to attract several clay particles. These clumps of clay with a lime core form crumbs, which make the soil much more porous than it was before treatment.

The number of particles attracted in a clump varies with the type of clay. In general, clays from northern climates produce larger crumbs. For example, I have seen photographs taken with an electronic microscope which showed eight clay particles clumped around a single lime core. Theoretically, then, a northern clay soil treated with enough lime to attract all the clay it contains should be eight times as permeable as it was before treatment. This degree of improvement is, of course, never reached in practice.

On some southern clays I have found that an application of as much as half a pound of ground limestone to a square foot (500 pounds to 1,000 square feet) has in most cases loosened them to a surprising degree without raising the pH excessively. If you use anything like this much lime, I recommend that you make a soil pH test in a month or so, just for safety. If the test shows the pH is too high, sulfur can be used to reduce the reaction without seriously affecting the crumbs of clay and lime.

pH AND THE COMPETITIVE ABILITY OF PLANTS

Logically then, rhododendrons and other ericaceous plants (broad-leaved evergreens) thrive in acid soil because their roots can take up the form of nitrogen available to them in acid soil. Such plants also have a high iron requirement; iron is an element which becomes less and less plentiful as alkalinity increases. Here, then, is a key to the competitive ability of various species of plants. We expect to find rhododendrons and azaleas ablaze on acidic granite ridges in the Great Smokies, while clovers thrive on lime-rich soils in the Middle West. We seldom see clover growing well in New England except where farmers have applied lime freely. Thus pH has a way of determining the appearance of our native landscape by favoring one group of plants over another.

CHAPTER DIGEST

Soil pH is a scale of acidity-alkalinity that is neither complex to understand nor difficult to use. Relative acidity affects many aspects of soil use and plant productivity. Make pH tests of separate samples of soil from different parts of your property; do not mix the samples. Use a home "do-it-yourself" test kit if your budget cannot stand the cost of professional testing of numerous samples. Investigate first, however, for your state agricultural station may offer the service free. Armed with test results and the knowledge of pH presented in this chapter, you can manipulate applications of lime, sulfur, organic matter and fertilizer to best advantage so that your soil will favor desirable plant growth.

Chapter 3

Various Soil Tests—Pro & Con

THE pH test is not the only one. Your soil's structure, organic composition, mineral (nutrient) content—all can be tested by various methods, with home kits or professional equipment. My principal objection to the use of most "all-purpose" home garden soil test kits is that the readings they give mean very little unless interpreted by someone who is experienced in the techniques of testing.

I often encounter the effects of a delayed action fuse of Christmas-gift soil test kits—usually in late March or early April. Up to that time, bad weather has prevented the gardener from trying out his gift kit, but as the soil thaws he rushes eagerly forth to do battle with his soil problems. Soon he is in a state of desperation because his soil seems to have gone to pieces over the winter. His tests show excesses or shortages of nitrogen, phosphorus, potash, iron—almost everything—and some of the readings run right off the chart.

On questioning him, I find he has grown good plants in the past (that's natural, for soil test kits usually are given to better gardeners), and he says he has never before noticed any serious deficiency symptoms. My advice to him is to sit down and drink a cup of coffee and forget soil tests until early June. Then test again, and the readings will be satisfactory. The reason for his "problem," as mentioned before, is simply that cold slows up or stops bacterial action, which throws the soil (and thus the tests) way out of kilter.

In my opinion, as far as chemical testing is concerned, gardeners should confine themselves to a simple acidity-alkalinity pH check. If the dollars spent for chemical toys such as "complete" soil test kits were spent on fertilizer instead, gardeners and gardens would be much better off. This is not meant to be a blanket condemnation of testing. A farmer who is growing hundreds of acres of corn or wheat often saves himself hundreds of dollars by acting on the results of a soil test. Usually, however, if he is not himself a university-trained man he has the help of his county agricultural extension agent who not only knows how to make actual tests, but to read them. He usually tests in fall at which time soil can best be checked for shortages of essential minerals as well as for pH. If lime is needed, ground limestone can be put on in fall and will have time to act so that an accurate reading can be taken the following spring to see if more is needed.

For home gardeners who still insist they want their soils tested, a list of state agencies is included in the Appendix.

TAKING A SOIL PROFILE

If you have serious soil drainage, compaction or structural problems, it may pay you to take a soil profile. This is done simply by digging a pit into a "central" area of the garden to get an over-all idea of what lies underneath the topsoil. The pit ought to be at least two feet deep and wide enough so you can get down in it to "read" the soil profile.

At the top of the profile you will see the dark layer of topsoil (unless a building contractor got rid of clay from an excavation by spreading it over your lot, in which case a layer of hard, stiff, light-colored strata will overlay the darker topsoil). Sometimes, in semi-arid regions, topsoil may be lighter than layers underneath but this is rare in any soil where garden plants will grow.

The depth of the topsoil usually shows how deeply roots of grasses and shallow-rooted weeds have penetrated. In prairie soils where bluegrasses often penetrate as deep as two to three feet, a surface layer of that depth is often found. The darker color of the topsoil indicates where perishable plant tissue has decayed, leaving behind a residue of humus and carbon.

In the soil scientist's language, this upper layer is called the A horizon. In many soils, just below it is another darker layer, but separated from it, which is called the A_x horizon. In some soils, where organic matter is tightly held by the topsoil, no well-defined A_t horizon develops. In such cases the next lower layer is the B horizon or subsoil. The science of pedology makes a great deal of these horizons. From them, earth scientists can read the history of soil formation. However, our interest is in checking depth and condition of the topsoil and the subsoil.

WASH TESTS

I am often asked whether a wash test cannot be used by the home gardener to see what materials make up a given soil. A direct yes or no answer is not possible. Light sandy soils containing little clay are easy to check in this way. The heavier the soil, however, the less accurate a wash test will be. The difficulty lies in breaking the bond between the acid clay particle and its cluster of alkaline particles. However, I find that if two tablespoonfuls of sodium nitrate are added to the soil sample, some of the electrical charge holding clay and lime together can be neutralized.

To make a wash test, use a half-gallon mason jar. If any other type of container is used, be sure it is round so the water and soil can be swirled around rapidly. Put half a cupful of soil into the jar and then half fill it with water. Pull down the top tightly and swirl the soil and water for half a minute. Allow this to settle and then swirl again. Repeat several times.

With each mixing, more and more coarse particles will drift to the bottom and more and more clay particles will drift to the top, with silt settling out between them. Some of the clay particles may not settle out for several days: they are so fine they form a colloidal solution in water.

Interesting information on a soil can be uncovered with the wash test. For example, a soil which one gardener complained was always cracking and was so high in clay he couldn't work it, produced an entirely different picture when washed. It contained only about IS per cent clay, but about 45 per cent silt. In this proportion, clay and silt particles intermeshed so completely that they worked like the cement in a concrete mixture. The addition of steamed cinders to this soil worked wonders with its texture.

In soil testing laboratories, where samples are dried and sieved into their component parts, a much more accurate reading is possible, but these tests are not necessarily of more value than the simple home-made wash test which gives a pretty good idea of the proportions of various soil ingredients.

FERTILIZER ELEMENT TRIALS

Serious students of soils will want to find out how plants respond to various fertilizer elements. A lawn is the best place for such investigations. Tests of chemicals are not difficult but do require the use of an accurate fertilizer spreader. The hopper is filled with a chemical that supplies only one fertilizer element and a strip of it is laid down across the lawn. Other single-element chemicals are applied in the same way, until the entire lawn is covered with strips of various elements. Be sure to leave one or more grass strips untreated to serve as a check.

Next, apply strips of the same materials in the opposite direction, creating a checkerboard. This will give a reading both of single elements such as nitrogen, phosphorus, potash and others, as well as of any stepped-up effect when two are used in combination. Results of tests of this kind are often surprising. Certain treatments show little or no response while others will produce dark green islands of vigorous growth among the other tests. Usually the combination giving the best response is the one for your soil.

Fortunate owners of small greenhouses can run similar tests indoors during the winter to give a clue to treatments for the entire garden the following spring.

TISSUE TESTS

The testing of plant tissues, particularly leaves, for nutrient levels is usually carried out for farm operations rather than for the home garden, but occasionally a friendly county agent can be found who knows the technique and will "read" your feeding efficiency. Foliage tissue tests are particularly valuable because they show the rate at which food is being taken up by the plant. Such tests can detect a nutrient deficiency long before the plant itself begins to show it. (See Appendix for a fuller discussion of this testing method.)

CHAPTER DIGEST

An answer is given to the controversial question of "to test or not to test" the soil; excluding pH tests made with inexpensive home kits, the answer is "don't bother." There are too many variables involved in testing for nutrients and other conditions, and a non-scientific gardener can easily misinterpret the test results. Professional testing, of course, is costly but can be relied upon. Soil profiles and wash tests are practical ways for the home gardener to find out about his soil makeup.

Chapter 4

What You Should Know About Nutrients

NITROGEN, phosphorus and potash are the "big three" of the many nutrient elements needed in the soil by plants for proper growth. These three are listed by numbers in that order on every package or bag of fertilizer (thus a 5-10-5 fertilizer product contains 5 per cent nitrogen, 10 per cent phosphorus and 5 per cent potash or potassium).

These "plant foods" do not occur as pure elements but as compounds with other chemicals. These compounds may be simple or quite complex but they share one quality—they can be attacked by bacteria, fungi and other organisms and broken down into quite simple products which plants can absorb. A fundamental quality of these simple products is that they must be soluble in water.

THE WAY PLANTS FEED

If we are to understand how plants feed, an old misconception must be discarded at once. Plants cannot "eat" the way animals do. Plants have no alimentary canal, no means of using undigested organic compounds such as protein, bone, straw and other "foods" applied to soil to supply them with nutrients. Even after such materials have gone through thorough decomposition in a compost pile, they may need to be broken down or rotted still more before their complex protein can be reduced to "available food" for plants.

Whether we call this process "decay," "digestion" or "organic breakdown," it involves exposing plant and animal wastes and by-products to soil organisms. These use part of the foods for their own life processes, but leave behind less complicated materials as end products. These simpler materials are water soluble and can be taken up by roots of plants.

Another widely believed misconception is that plants reach out for fertilizer in the soil, drawn by some force which tugs at the roots. Vivid proof that this is not so was shown to me in the studio-greenhouse of John Nash Ott who photographs plant growth in lapsed time. Plants were growing in a soil-filled box with a glass front which allowed a clear view of the roots. Fertilizer was placed here and there in the soil. But the roots grew in various directions, apparently unaffected by the fertilizer. In fact, it could be seen that some roots had passed within a fraction of an inch of one concentration of fertilizer.

Perhaps the most complicated substance plants can use directly is ammonia, a relatively simple molecule of nitrogen and hydrogen. Rhododendrons and other acid-soil plants can use ammonia directly, but many others require it to be broken down still further into nitrate nitrogen.

Contrast this simple chemical with the protein molecule, so complex that it offers all-but-insurmountable obstacles to chemists attempting to synthesize it. Contrary to what many gardeners think, direct absorption of such a complex molecule is beyond the capacity of any plant root. (One apparent contradiction of this statement is the capture and absorption of insects by certain insectivorous plants, such as the Venus Fly Trap and the Sundews. Insects are lured into special organs where they are caught and "digested" before being used by the plant as food. However, the digestive organ of these plant oddities is a specialized leaf in which protein is fermented into ammonia and nitrogen compounds. These can be absorbed by the leaf and used just as these compounds are used when absorbed by other plants through roots.)

To repeat (and it's worth repeating), the simple nitrogen compounds which garden plants always need, the phosphorus they use at certain stages of growth, the potash so vital to woody plants, the sulfur so often ignored in discussions of plant nutrition, and several other chemicals vital to plant growth must all be in soluble form. Otherwise they are as inaccessible to plants as if they did not exist. This does not mean that the best material is the most soluble. Often we need *controlled* solubility—especially with nitrogen—to give a longer feeding period.

MIGHTY NITROGEN

Of all food elements needed by plants, none is more important than nitrogen. It is popular to call the "nitrogen cycle" (a process by which nitrogen is used and reused, over and over again) the most important single biological process in the world. While the nitrogen cycle *is* vital to the continued existence of every living organism, it is, of course, only one of several such basic processes, none of which could be halted without destroying all life.

Nitrogen is so important to plant nutrition that its concentration in a given soil tends to be the # 1 factor which controls growth. What we call a worn-out soil is often the result of farming or gardening practices which have exhausted native reserves of this vital element and made no provision for replacement. Nitrogen usually determines whether a soil is rich or poor, whether yields will be high or low.

One reason why nitrogen is so important is that it is essential to all tissues involved in growth and reproduction. Research has proved that the rate of growth in plants is more dependent upon this element than on any other single material.

WHERE DOES IT COME FROM?

We may talk glibly about organic versus inorganic nitrogen, but regardless of whether it occurs as part of animal or plant protein or as any other nitrogen compound, every atom of nitrogen came originally from the atmosphere. Once captured from the skies (whether precipitated by lightning or trapped by a nitrogen-fixing organism), nitrogen must be built into plant protein in order to be available to living organisms. Animals are wholly dependent upon plants to supply them with nitrogen; animals cannot use the simple nitrogen compounds which plants extract from the air.

The atmosphere does not give up this element lightly. Although above every acre of soil there floats a reserve supply of about 150,000 tons of free nitrogen, this is almost totally inaccessible to plants. Minute amounts are brought down as fixed oxides of nitrogen by powerful lightning flashes. Certain soil-inhabiting bacteria, which are primitive plants (though lacking in the chlorophyll of their higher relatives), are able to fix nitrogen from the air. Other bacteria (those that form nodules on roots of legumes like clovers, peas, and beans, to name a few) are also able to convert this element into a form which they use for their own growth, supplying what is left to their host plants.

Except for a miniscule amount of nitrogen fixed electrically by man, these limited sources (limited in comparison with the vast unused store floating above) must satisfy the craving of every living thing for this vital ingredient of existence. Once captured, it might not be held for long, since each time nitrogen is converted from one form to another, it struggles to escape.

THE NITROGEN CYCLE

An intricate pattern is traced by nitrogen as it is captured, used and released by plants and animals. This is commonly called the nitrogen cycle. At each stage some nitrogen returns to the atmosphere directly because not all of it can be used. Thus, while we call this a nitrogen *cycle,* a complete recycling through all stages without some return to the atmosphere is never achieved.

Atmospheric nitrogen can enter soil in one of two ways. The first is by direct precipitation from air when the nitrogen is fixed as oxides by electrical discharges during thunder storms. The second is by fixation by specialized soil bacteria or by other forms of bacteria that live on the roots of legumes.

When plant roots absorb nitrogen which was previously fixed by one of these two processes, it is converted into protein by the plant. Any unused portion may return to the atmosphere or be blotted up by avid soil bacteria and fungi which are not specialized and thus cannot fix their own supply. Animals feed on plants, but are continually returning matter (and finally their bodies) to the soil to be reused by other plants. No living thing can escape dependence upon the nitrogen cycle.

MANNA FROM THE SKY

An old French saying my mother taught me, as I protested against bad weather in spring that kept me from outdoor play, went something like this, "April snow is as good as sheep manure." This holds more than a grain of truth, since spring rains and snows do bring down nitrogen in oxide form from the atmosphere. According to figures collected at various stations throughout the world, the amount brought down may vary from 2 to 8 pounds per acre.

Since fertilizing was a big problem for Old World farmers, they learned to leave their fields rough-plowed (with large clods) in fall, to allow winter rain and snow to enter and penetrate the soil quickly, so this manna from the sky would not be lost.

In home gardens today, rough plowing just for this purpose would not be worth while, since less than an ounce of usable nitrogen per thousand square feet would thus be captured. Most of us throw away more than that much nitrogen in the dust that clings to the empty bag of low-cost, easy-to-use fertilizer.

Nor would a present-day farmer find it profitable to rough plow for this purpose alone. The capture of 2 to 8 pounds of nitrogen per acre would not make much of a dent in the 150 pounds or more per acre he would have to replace after harvesting a 100-bushel corn crop. This does not mean that rough-plowing in fall is obsolete, but today we continue this operation because of other benefits which justify it.

RESTORING NITROGEN

Before modern chemistry came to the rescue, farmers and gardeners had two ways to replace nitrogen consumed by crops. One was to use manures and other animal wastes in amounts as large as could be afforded. I recall, as a boy, walking many blocks to find livery stables and grocery delivery barns where manure was being thrown away and could be had for the hauling. Our own mare, a prodigious "oat burner," could not produce this precious stuff fast enough to maintain our one-acre vegetable garden and home orchard. In the race for this largess I had to compete with half a dozen neighborhood boys. Only our next-door neighbor, the local banker, who kept both a team and a milch cow, was exempt from this competition.

Manure is still valued in many places in the world, as witness the Pennsylvania Dutch farmers and French peasants who accumulate it as a miser amasses gold. In America, the automobile, the growth of city and surrounding suburban areas and other factors have conspired to make barnyard manure almost unknown to millions of gardeners.

The only other nitrogen-replacement method available to farmers up to the nineteenth century was to grow cover crops of legumes such as clovers, alfalfas, peas and beans to capture atmospheric nitrogen through the bacteria growing on the roots. This practice was once part of the farmer's bible, but is slowly falling into disuse. Modern farmers find it much more profitable to apply one dose of low-cost liquid ammonia—the work of a few minutes—than to devote every second or third year to growing cover crops that bring no cash return. (In mentioning this modern trend, I am by no means giving it unqualified endorsement. I cannot help but feel that in our rush for cash income we are exhausting basic fertility in soils, using up elements which *seem* less critical than nitrogen, yet, when gone, will cause decreases in yields just as surely as will a nitrogen deficiency.)

Fortunately, today's gardener does not have to raid manure piles or grow cover crops in order to maintain soil fertility. For the price of a couple of movie tickets, the home grower can replace all the nutrient elements he removed in a year's harvest. The average garden plot is so small and fertilizer cost is such a minor factor that any elaborate organic system of conserving nitrogen would be pointless (except, of course, that a program of conserving and augmenting organic supplies in soils is essential for many other reasons).

NITROGEN RESERVES IN SOIL

The "furrow slice" (the depth to which a horse-drawn plow could "bite") was set years ago at seven inches. In richer, heavier soils, nitrogen tends to accumulate in this upper layer. On rich Midwestern prairie loams, a furrow slice may contain as much as 7,500 pounds of nitrogen per acre. The next lower seven inches may hold only half as much, while the nitrogen content seven inches lower is down to 25 per cent of that of the furrow slice.

In lighter soils, this accumulation pattern is reversed. The more sand and gravel a soil contains, the deeper into the soil the nitrogen tends to move. This is important to know when handling such a soil.

It suggests the importance of double digging and trenching (two soil-improvement operations described in Chapter Twelve) to bring the richer layer to the surface. Too, it suggests the value of growing deep-rooted plants which can penetrate to the layer where nutrients have accumulated.

ORGANIC NITROGEN COMPOUNDS

During the warm-weather times of the year, when soil bacteria and fungi are working at top speed, ammonia and nitrate nitrogen are present in the soil in considerable amounts. Nevertheless, most of the nitrogen in soils exists as organic compounds. Although a plant's root system cannot "eat" them, these compounds still are valuable sources of nutrition (as discussed in Chapter Five). Organic compounds are mentioned briefly here because they often give a false picture of fertility when the soil is tested, particularly when the analysis is turned over to the beginner without explanation.

In a fertile, humus-rich soil, availability of nitrogen will vary from season to season or even from day to day. In early spring, none may seem to be present because all the free nitrogen has been taken up by soil organisms. With practically no bacterial or fungal action going on in the cold soil, nitrogen is not released. Weekly tests as the soil warms up will show a gradually increasing nitrogen supply, with a high point late in June (in the region north of the Ohio River). This levels off soon thereafter and gradually subsides until July, when a sharp deficiency of nitrogen may be registered (a partially false reading). If summer rains are abundant (preventing drought-death of soil organisms) this leveling-off in July may not take place. When cooler weather comes in fall, nitrogen will again accumulate as plants use less and less of it. Yet the surplus will again gradually be blotted up by bacteria, fungi, actinomyces and protozoa, until a nitrogen "deficiency" is again registered.

Farther south, where soil organisms can attack organic matter over a much longer period, it is soon used up, so that its end product —humus—has little chance to accumulate. In tropical countries, where decay is continuous, humus formation is a negligible factor in soil fertility.

PHOSPHORUS: AN ELUSIVE ELEMENT

Although our knowledge of how plants actually use phosphorus is still elemental, we are much better off than we were just before World War II. Production of radioactive forms of phosphorus in atomic piles has made possible a study of its movement through plant tissues, unlocking many secrets of a decade or more ago.

Why is phosphorus a difficult element to maintain in soil in a form that plants can use? It is extremely quick to react with—and be locked up by—other chemicals. In fact, experts estimate that less than 1 per cent of the total phosphorus reserves of a given soil are ever used.

We once thought that phosphorus was used by plants only as they approached maturity and was not essential to young growth. Old garden books are full of recommendations for "hardening soft growth" with phosphorus (and potash). You may still see references such as "apply phosphorus to tomatoes toward maturity to 'firm up the fruit.'" Many special dahlia and potato fertilizers were low in nitrogen but high in phosphorus because phosphorus was thought to bring about earlier maturity. Actually, young growth in particular needs phosphorus. It is so essential to such growth that if it is not present in sufficient quantities for all parts of the plant, it will be withdrawn from older leaves and translocated to more active growing tips and young foliage. For this reason, a phosphorus deficiency is among the first things that plant nutritionists suspect when a plant's lower foliage is poor but younger leaves seem normal.

Phosphorus is a major ingredient in the nuclei of cells, and is present as well in cytoplasm surrounding each nucleus. We know that phosphorus has something to do with transfer of inheritance factors from one generation to the next. Exactly how it works, we do not know.

OUT OF BALANCE

For all its importance, phosphorus is removed by plants in amazingly small amounts compared with amounts applied to soil in order to supply it. A crop of corn may remove less than 25 pounds of phosphorus per acre. Yet to supply that amount, between 200 and 300 pounds of superphosphate may have to be applied. Hay may remove only 2 to 3 pounds of actual phosphorus from an application of 50 to 100 pounds of superphosphate.

Because of its tendency to lock up, phosphorus accumulates when high-phosphate fertilizers are used regularly. I have seen analyses of lawn soils from the Chicago area, where such fertilizers had been applied for several years without letup, in which the phosphorus content was so high that the soil itself could have been used as a low-grade source of that element!

An old-time phosphate fertilizer is bone meal. It is still used by many, but is a poor value because of its low solubility. It is often said that one application of bone meal will last in soil for 15 years—which is presented as an argument in its favor. (The pros and cons of bone meal are discussed under fertilizers in Chapter Five.) I know of an instance of bone meal remaining virtually unchanged in the soil for half a century.

NOT ALL IS LOST

Even though they may be locked up by chemical action, all forms of phosphorus are not lost forever. True, certain combinations with iron or aluminum are so highly resistant to change that they can never be dissolved by any chemical that would be safe to use on soils in which plants are growing. Other phosphorus compounds, however, such as fluorapatite and hydroxyapatite, do become available by weathering, by bacterial action and by exposure to soil acids and alkaline solutions. For example, raising the pH of an acid soil from 5.5 to a reading of 6.4 increased the availability of phosphorus to ten times the original level. In another case, reducing the pH of a higher alkaline soil (from 8.3 to 6.9) resulted in a 500 per cent increase in phosphorus availability.

PHOSPHORUS DOES NOT MOVE

One difficulty experienced in supplying phosphorus to plants is its lack of mobility in soil—a result of its low solubility. Phosphorus may become slightly soluble and move somewhat in soil water, but even when this happens, it will hardly have time to move far before it is fixed in less soluble form. For this reason, *if plants are to obtain enough phosphorus, their roots must grow out to meet it.* Phosphorus is the mountain, roots are Mahomet.

Because phosphorus moves so little once it is in contact with soil, placement is highly important. The usual practice of scattering superphosphate on top of the soil is of little value, at least to the current growth. Because it is so stable, the phosphorus will still be in place, unused, when soil is prepared the following year.

Adding superphosphate to topsoil just before spading or tilling does have the virtue of getting some of it down into the ground. However, any of the material that remains above the area in which roots grow is of no use to them.

For maximum use, the best placement for phosphorus fertilizers is in the soil, worked down deeply *before planting.* It should be as close to the root zone as possible. For shallow-rooted plants such as petunias, lettuce or alyssum, this means within 3 to 4 inches of the surface, but for deep-rooted woody plants, such as trees and shrubs, it might mean working in superphosphate to a depth of 3 to 4 feet.

IN THE LAWN

Soils for lawns present a special problem. Mistakes in feeding vegetables and annuals can be corrected a year later, but it is not easy to roll up an established sod to incorporate superphosphate. Since it does not move downward, phosphorus in liberal amounts should be used in original lawn soil preparation, with hopes that this will become slowly available through the years.

On lawns, maintaining proper pH will be of tremendous help. Fortunately, superphosphate is not harmful to roots and can be used liberally to build up a reserve for the future.

ORGANIC MATTER TO CONSERVE PHOSPHORUS

One of the roles of organic matter is conserving phosphorus. Organic matter keeps up soil moisture. A characteristic of phosphorus is that when it exists as small crystals, it is much more soluble than when larger crystals form. In moist soil, smaller crystals are formed. These go into solution more readily.

Too, as organic matter decays it produces certain organic acids such as tartaric, isocitric, and so on. These combine rapidly with any free iron and aluminum to form metal-organic ions which do not combine readily with phosphorus. By using up free iron and aluminum, these acids prevent formation of less-soluble compounds of phosphorus.

In addition, organic matter itself contains considerable phosphorus, the amount depending upon the origin of the organic compound. As cells of decomposition bacteria and fungi die, they release their phosphorus for use by higher plants.

The amount of organic phosphorus available varies from time to time. If liberal amounts of nitrogen are present, soil organisms may increase so rapidly that instead of releasing nutrients they will use up all surplus food and cause a temporary shortage. Fortunately, the life span of these organisms is short, so that plant roots will not have to wait long before the food elements are again available.

PHOSPHORUS IN EARLY GROWTH

Because phosphorus is needed by young plant growth, it should be applied early in the season. At least half the total annual phosphorus consumption by annuals and perennials will be absorbed before these plants have made one-fifth their annual growth. In case of grasses, early uptake may be even higher: perhaps 80 to 90 per cent of their annual consumption will be taken up during the first few weeks of growth.

This need for phosphorus early in the growth cycle poses a problem. Phosphorus should be supplied just before it is needed, but not too far ahead of need. For grasses and perennials, this means in early spring. Bedding plants, however, and tender vegetables such as tomatoes, eggplant and peppers usually are not set outdoors until early June. Superphosphate worked under in April would already be combining in less soluble compounds by June, and so would not be of maximum value to these late-set plants.

Here the so-called transplanting solutions serve a useful purpose. These are chemicals to be dissolved in water and applied to seedlings as they are transplanted. These solutions are low in nitrogen but high in phosphorus. They are completely soluble and are taken up by seedlings and transplants before phosphorus fixing can take place.

GROWTH PATTERN OF WOODY PLANTS

Trees and shrubs do not seem to benefit from spring applications of phosphorus (and other nutrients) to the same extent as other types of plants. This is no doubt due to their different growth pattern. That tremendous canopy of leaves produced so quickly in spring by a mature elm could not possibly be manufactured from foods absorbed from cold, wet spring soil, in which most nutrients would be locked up and unavailable. Instead, this growth comes from food stored in tissues a year before. Maple sap is a case in point. Its sweetness as it is tapped for maple syrup in late winter comes from natural sugars stored the previous summer.

Growth of trees begins with elongation of terminal buds and leafing out of dormant foliage buds long before bacteria can begin their work in the cold soil around the tree roots. It is not uncommon for maples, for example, to finish their flowering and produce their first leaves before the last traces of snow have disappeared. Twig elongation and production of new leaves continue without interruption until about August first north of the Ohio River, and for about two weeks longer south of that line.

QUICKLY AVAILABLE IN SOLUTION

About August first, most trees will shed a few leaves as though anticipating autumn. Most of the foliage, however, continues to function in food manufacture, but twigs stop growing in length. Instead, they begin to swell in girth. This indicates a storage of starches and sugars in the wood, a process which continues until frost kills all foliage. Almost the last act of the growing season is a withdrawal of all food from the leaves and a halt to chlorophyll formation, thus bringing on the pageant of fall foliage color.

If soluble phosphorus is applied in summer, just before twigs start to increase in diameter, it will be stored along with elaborated starches and sugars, ready for next spring's burst of growth. If, however, it is applied in spring, it will not affect growth a great deal and, by August, it will be locked up and of little use to the tree.

POTASH: THE THIRD "ESSENTIAL"

Potash is classed with nitrogen and phosphorus as one of the three essential (major) fertilizer elements. This seems surprising in light of the relatively small amounts of potash removed from the soil by some crops. A 25-bushel per acre oat crop, for example, removes only 5 pounds of potash. Yet this element is highly important to several basic functions in plants.

It helps check the tendency of nitrogen to produce soft, rapid growth. It is essential to formation of starch and sugar and to transport of these materials inside plants. Plants fed liberally with potash suffer less in drought. Potash stiffens cereal straws, increases oil content of oil-bearing seeds and has an important role in plant protein formation. Plants which store starches and sugars in tubers or corms, such as dahlias and potatoes, quickly show injury or decline when they are suffering potash deficiency. Later, the keeping qualities of the tuber, bulb or corm will be seriously affected if potash is too low for normal growth.

Other types of plants do not readily show signs of potash shortages. If soil is only slightly deficient in potash, plants tend to remain smaller in all parts, yet they flower, fruit and reach full maturity. It is only when potash-deficient plants are compared directly with those fed liberally with potash that the difference can be seen.

Some crops do use rather large amounts of potash. A single acre of celery may use up as much as much as 200 pounds. On the other hand, grain may remove very little if the straw is plowed under. An excellent way to maintain potash reserves is to return all plant residues to the soil.

In the home garden a well-managed compost pile can produce organic matter that will help to sustain potash in the soil, particularly if extra table wastes are added to the refuse gathered from the garden. A lawn on which clippings are allowed to remain will need to be fed only half as much potash as needed by an always cleanly raked lawn.

CLAY SOILS RICH IN POTASH

Clay soils may not always show a response following addition of potash fertilizers. Clay particles hang onto this element tenaciously, yet release it readily to plant roots. When fertilized regularly, clay soils tend to accumulate potash, since rates recommended for most crops are usually made with sandy soils in mind.

In home gardens, regular use of a good mixed fertilizer plus additions of compost should insure all the potash needed. Sandy soils, particularly if strongly acid, are another matter. Sandy soils, mucks and peats have little or no reserves of potash on which plants can draw, and little capacity to hold what is applied. For this reason, fertilizer applications in such soils should be split, so that about one-fourth of the potash goes on in early spring, half in mid-summer and the final one fourth as crops are nearing maturity. While potash is vital for early growth, not much is used at this stage. Toward maturity the demand is much greater. Thus, if all of it is applied in spring, a shortage may develop by fall on sandy soils.

HEAVY APPLICATIONS SOMETIMES NEEDED ON CLAY

Following World War II, a rush to suburban living absorbed millions of acres of farmland around American cities. Many farm owners, realizing what was going to happen, stopped regular soil maintenance and let crops use up fertility that had been built up through the years.

In such soils, potash (even on heavy clays) was depleted to a point where deficiency symptoms developed. I have seen a number of speculative housing developments where the minimum of black soil that was applied came from just such impoverished former farm fields. Heavy applications of potash were needed to bring the soil up to good tilth again. As a result, even where black clay soil is deep, I recommend that you apply extra potash if you are developing a garden in a new housing development. Once clay soil has been brought up to a high potash level, ordinary applications plus compost should keep it will supplied.

SODIUM VS. POTASH

Chemically, potash and sodium are enough alike so that many plants will absorb sodium if potash is in poor supply. This presents a problem in certain western soils where sodium is high. Large amounts of potash are needed in such soils to override the sodium and thereby keep plants from absorbing this useless and sometimes harmful chemical.

There are, however, a few plants which seem to need small amounts of sodium for normal growth. Among these are beets, cabbage, celery and turnips. If these do not do well, the use of nitrate of soda as a source of nitrogen will sometimes increase yield and crop quality.

Other crops, particularly asparagus and tomatoes, seem to be able to use a certain amount of sodium if potash is low, yet seem to be neither hurt nor helped by the substitution—up to a certain point. If sodium is too high, they will suffer.

In general, with these exceptions, sodium can be considered nonessential as a trace element and definitely harmful if present in quantity. In fact, many crabgrass-killing chemicals contain a form of sodium.

THE "MINOR" ELEMENTS

The word "minor" as applied to elements such as iron, boron, magnesium, calcium, sulfur, zinc and so on, does not refer to their importance but to the amounts present in soil for use by plants.

CALCIUM AND MAGNESIUM

Although used by plants for different functions, calcium and magnesium should be discussed together. They often occur in the same "limestone" used for "sweetening" acid soils. Thus when a liming has a favorable effect on plant growth it is hard to tell whether the improvement is due to changes in pH, or to the effect of calcium on plant cells, or to the vital effect of magnesium on chlorophyll formation.

In other cases, calcium may override magnesium and cause a deficiency. If present in excess, magnesium may also create a problem by starving the plant for calcium.

In areas where limestone is high in calcium and lacking in magnesium, it may pay to use finishing lime from a building-material yard to supply magnesium. A light dusting of finishing lime on the soil every second or third year should be enough, unless fertilizers high in sulfates have been used. In this case, an annual application of finishing lime may be needed to replace magnesium washed out as Epsom salts (magnesium sulfate). Epsom salts are highly soluble and readily washed out of soil.

Calcium is a vital plant nutrient, particularly during early growth. It is needed to form cell walls and to serve as a building block in protein. As might be guessed from its role in neutralizing soil acids, it also helps tame acids formed during growth which might otherwise harm plant tissues.

Magnesium, an essential element in chlorophyll formation, has been exhausted from many older cultivated soils. Overtiming with calcium, without also adding magnesium, may hinder chlorophyll formation in plants. To check whether magnesium is needed, mix a tablespoonful of Epsom salts to a quart of water and spray it on some foliage. If the leaves turn a darker green, a shortage of magnesium in the soil is indicated. A dusting of finishing lime between the plants (avoid hitting foliage and stems) will be of benefit.

NEGLECTED SULFUR

Sulfur is seldom mentioned in discussions of plant nutrition and is never listed as an essential ingredient on fertilizer bags. It may surprise you to learn that plants utilize sulfur as much as or more than they do phosphorus. For example, while a crop of cabbage may use up only 25 pounds of phosphorus per acre, it will extract 40 to 50 pounds of sulfur.

During the latter part of the nineteenth century, scientists believed that sulfur was not an essential plant nutrient. During that period, all analyses for essential elements were made by burning plant tissues and analyzing the ash. Since sulfur is volatile at ashing temperatures, it went out the flue and did not appear in the residue.

I was fortunate in being able to study under the great Cyril G. Hopkins during the last years of his life. It was he who pointed out that sulfur probably is washed down out of the atmosphere by rain and snow in much the same way as nitrogen oxides are precipitated. He predicted that no sulfur shortages would occur in areas where fumes from factory chimneys were belching this element into the air in quantities sufficient for normal growth.

In such areas, accumulations amount to about 50 pounds per acre a year. In areas at a distance from industrial centers, annual accumulation is less than 5 pounds, not enough for normal crop needs.

Fortunately, many fertilizer materials used today are sul fates and supply sulfur along with the element in combination with it. Requirements of some crops for sulfur are quite high, particularly those in the mustard family, the brassicas—alyssum, stock, candytuft, nasturtium, and hesperis among flowers, and cabbage, broccoli, cauliflower, radish, turnip, and kale among vegetables. Onions, too, need sulfur to develop their tear-jerking odor.

Sulfur is important because it is a basic element in protein manufacture by the plant. If it is in short supply, older leaves are robbed to supply younger, more active leaves and growing tips. If the plant continues to "starve" for sulfur, protein synthesis stops while amino-acids, cystine and other nitrogen-bearing compounds accumulate in plant tissues; these unused building blocks of protein cannot be set in final place for lack of sulfur.

Perhaps the second most important role of sulfur is in synthesis in the plant of the so-called plant hormones or growth regulators.

Home gardens seldom lack sulfur. In addition to sulfur washed down from the atmosphere, quantities of this element are provided by humus and other organic matter in the soil, or by the fertilizers that contain some sulfates, such as sulfate of ammonia and superphosphate. Thus, while sulfur is fully as essential as nitrogen, phosphorus and potash, it can be generally taken for granted.

IRON

Although the majority of garden soils are well supplied with iron, one of the most common plant troubles is a chlorosis or yellowing of foliage, a symptom of iron deficiency. This is due either to a lack of iron (in rare cases) or to a locking up of this vital element in a soil of too high pH. Iron chlorosis often appears with dramatic suddenness following an overdose of lime. Sulfur, as noted, plays a vital role in acidifying overly sweet soil.

As might be judged from its effect on green foliage color, iron plays an important role in chlorophyll formation. Since lack of chlorophyll prevents plants from manufacturing starch needed for energy and growth, iron-starved plants become unthrifty. Lime is therefore "verboten" where broadleaved evergreens such as rhododendrons and other acid-soil, iron-dependent plants are growing. Also, there is a still-undefined but apparently unfavorable relationship between iron and such elements as copper, manganese and zinc in the soil.

ZINC

Although plants contain and need as little as one part per million of zinc, this element is essential to growth of many plants and possibly to all. Its role in plant nutrition was discovered comparatively recently. Zinc deficiencies were first observed in Florida and California. Its most important role seems to be in seed formation. Peas and beans grown in zinc-deficient soils may form small, seedless pods. If some zinc was present in the soil earlier but was exhausted before flower pollination, plants make some growth and rob older foliage of zinc to mature the seeds formed when pods begin to set. Often enough zinc is "borrowed" so that a near-normal crop will be set on stunted plants.

Zinc also plays an important role in cell formation. When zinc is lacking, cells do not divide but continue to enlarge in size. Apparently, without zinc the nucleus is incapable of dividing to form new cells.

Like sulfur, zinc enters into synthesis of such vital products of plant metabolism as protein and plant growth regulators.

An unusual characteristic of zinc should be noted: It seems to be scarcest where organic matter is most abundant. Most other metallic minor elements such as iron and boron are more readily available in the presence of organic matter, but apparently this does not hold true for zinc.

BORON

Nearly 400 years ago, borax was shipped from Central Asia to Europe for use as a fertilizer—one of the first chemicals to be used in feeding plants. Despite this early use of a boron-bearing material, it was not until 1915 that boron's essential role in plant nutrition was fully established. Because boron is used in such minute amounts, modern chemical methods were needed to make the necessary analyses to detect its role. It is unique in that the lack of as little as one or two parts per million in soil may produce deficiency symptoms; and, conversely, if boron is present in concentrations of only 10 to 15 parts per million, it may be toxic. A ton of cut alfalfa will contain less than two ounces of boron drawn from the soil, but those two ounces are vital to alfalfa growth. If boron is not present, terminal buds of the plants die, forcing side shoots to develop. In turn, tips of these shoots die, producing a plant full of short stubs with dead ends.

Boron has other uses in plant nutrition, many of them critical. It enters into cell division, affects flowering and fruiting, stimulates pollen grains into germinating, affects translocation of water in plant tissues and enters into many metabolic processes. Like several other elements, boron is linked with calcium in its effects on plants. Symptoms of boron and calcium deficiencies are much alike. When calcium uptake is low, plants need less boron. When calcium use is high, boron deficiencies develop more rapidly. The two chemicals should be in a certain ratio to work well together—eighty parts calcium to one part of boron as maximum and 600 parts calcium to one of boron as a minimum. There is also evidence of a relationship between boron and potash, but the exact nature of this has not been clarified.

The addition of organic matter to soil releases boron that has been locked up in an insoluble form and makes it available to plants. Soil moisture also affects boron availability. As long as the soil is moist, boron remains soluble but in dry soil it reverts to an insoluble form.

Boron is credited with affecting fifteen different functions in plant growth. Certainly it is a mighty midget of an element.

COPPER

Copper is both a poison and a nutrient. One of the earlier chemical weed killers was copper sulfate. The famed Bordeaux mixture, perhaps the first chemical fungicide, is a copper material that is used to destroy a fungus, which is, of course, a form of plant life.

The fact that copper is a nutrient was not proved until 1927. About that time, lack of copper was proved to be the cause of a slow decline in vigor of citrus trees. Its lack seems to affect many functions of plant growth, yet its role has not as yet been well denned. Two places where it may be in short supply are in mucks and in sandy soils of Florida. One way to test whether copper is needed is to spray plants with a weak solution of Bordeaux mixture. If copper is lacking, a marked improvement in foliage color and vigor will be evident in a week. For soil treatment, an application of 10 pounds of copper sulfate per acre is recommended.

MANGANESE

Many obscure and puzzling diseases have been traced to manganese deficiency without too many clues as to how this affects plants. Recently, chlorophyll research with radioactive isotopes has shown why the lack of manganese causes so much trouble. Along with iron, it is vital in chlorophyll formation and, if it is missing, production of starches and sugars is severely checked.

In most cases, manganese deficiency alters the color of foliage in some way. When leaf veins remain a dark green but areas between veins turn yellow or brown and finally break up, you can suspect a lack of manganese. It is seldom toxic when present in excess but in tobacco fields in Kentucky and Connecticut signs of poisoning have been noted. Again, leaf color is affected, with severe chlorosis and yellowing of the foliage.

Overtiming is often a cause of a shortage of manganese since this element readily locks up (becomes insoluble) in alkaline soils. Formerly the addition of sulfur was recommended when manganese deficiencies were suspected. This worked only if manganese was present originally and had locked up because of too high a pH. Thus when this element seems to be needed, lowering the pH to about 6.0 by the addition of sulfur is recommended. The manganese itself is supplied by applying 10 pounds of manganese sulfate per acre, or four ounces to 1,000 square feet of garden area. If the soil is already acid, 3 to 5 pounds of manganese sulfate per acre should be enough.

MOLYBDENUM

Although needed in fantastically small amounts (an ounce will supply enough to fertilize an acre for several years!), molybdenum is being recognized more and more as a vital micro-nutrient. Its most important function is to help certain free-living bacteria to fix nitrogen directly from the atmosphere, without the need for growing a crop of legumes. True, this molybdenum action is hardly a major source of nitrogen, but moly (as it is called for short) is needed for other purposes anyhow. If a soil contains none of it, clovers, tomatoes, certain fruit trees and a number of other plants will not grow. The amount needed is one part in 100,000,000 parts of soil, yet this barely-detectable bit of molybdenum is critical.

Unlike many other metallic elements, moly is released by liming. Normally, soils which are limed regularly are not deficient in molybdenum.

OTHER ELEMENTS

At various times in recent years, other elements have been studied in relation to plant nutrition but the need for them is not well established. Cobalt, for example, is taken up by plants but plants grow well without it. It is, however, essential to animal growth and lack of it in forage plants causes serious deficiency diseases in cattle. These ailments go by such names as salt-sickness, bush-sickness, pining, pine, vinkish and dasing (the last four are English dialect names) and marasmus (in Australia).

Certain plants need some chlorine to grow but this element is so often present in fertilizers, table wastes or organic matter that it is never deficient in garden soils. Iodine and fluorine have not been proved essential, although they are absorbed by most plants.

TOXIC EFFECTS

Arsenic is an element which is likely to be toxic in soils. Where an apple orchard has been sprayed for years with lead arsenate, arsenic can build up substantially. This seems to do very little harm to apple trees, but if the area is later subdivided, home owners may have a hard time growing grass or other plants on the contaminated soil. Arsenic is taken up by plants in place of phosphorus but does not substitute for it nutritionally.

Another place where arsenic can be harmful is on old golf courses. Lead arsenate is used for grub-proofing turf and also to control knotweed, crabgrass and annual bluegrass *(Poa annua).* If used year after year, arsenic may build up and override the intake of phosphorus by plants, thus starving them for that element. Growth will be retarded, plants will be stunted and they will mature late. Very sensitive plants, such as the stone fruits, may show injury in the form of shot-holes in the leaves or as marginal scorch.

The remedy for arsenic-sick soils is not easy or cheap: it involves application of as much as 500 to 1,000 pounds per acre of superphosphate. Or the same amount of iron sulfate can be applied. However, superphosphate is not only cheap but safer; iron sulfate used at this high rate will badly injure or kill grasses in lawns; in fact it was once recommended as a weed killer.

Selenium, molybdenum, fluorine and lead also are taken up by plants. These elements are poisonous and thus can harm humans (or animals) who eat contaminated plants. About the only time these elements need concern the home gardener is when they get into soil in the vegetable plot. The most dangerous of these elements is selenium, used by many African violet growers as a soil insecticide. It works beautifully for this purpose. However, selenium *is* a dangerous and lethal chemical. Never discard a plant grown in selenized soil (or the old soil itself) onto the compost pile. There is too much chance that some of the treated soil will eventually wind up in the vegetable garden, where it could be responsible for sickness and death.

CHAPTER DIGEST

Nutrients are commonly called "plant foods" but, like human food, they must be broken down or "digested" into simpler forms before plants can use them. Soil bacteria and fungi perform this essential job. Abo, plant roots can only take up nutrients in solution, so everything must be soluble in water. Nitrogen, phosphorus and potash—the "big three"—plus a number of "minor" elements play definite though often inter-related roles in plant growth. A properly fertilized soil is one in which these elements are always available in amounts adequate to assure maximum flower and "fruit" as well as vegetative (stem and leaf) development.

Chapter 5

Soil Fertilizers—Uses and Sources

A COMMON illusion about fertilizers is that they are direct nutrients which must be promptly absorbed or they will be lost (either leached out of the soil by rain, or locked up in some insoluble, unusable form). The fact is that instead of being used directly to any extent, most of the nutrients in fertilizer compounds are quickly blotted up by soil organisms such as bacteria, fungi, protozoa and actinomyces. Gardener's Loam contains billions upon billions of such organisms which occupy the soil mass so completely that very little in the way of soluble plant food can escape them. They act as reservoirs of fertility, releasing it when they die. Since their life span is short, such food is not tied up for long periods, but merely saved for later use by plants. The role of microorganisms in conserving fertility cannot be overestimated.

The ideal fertilizer would be one that supplied every needed element of nutrition for the crop being grown, at a rate that would take advantage of all available light, heat, moisture and oxygen needed by plants. This ideal material would supply some nutrients in quickly-available form for immediate growth, yet would contain other nutrient fractions that would be released so slowly that a single application in spring would continue to feed until cold stopped plant growth in fall. All through this cycle of combined slow and fast release, enough surplus nutrients would be given off to provide food needed by soil organisms to carry on their functions.

Claims for various materials are endless and often self-contradictory. In general it may be said that chemical and mineral fertilizers are more readily available for immediate use by plants, while organic materials (which must undergo more involved decomposition before they can be absorbed) are slower in action and last longer in the soil. These distinctions are being gradually eliminated by the development of long-lasting chemicals that release fertility even more slowly than some organic manures.

FERTILIZER BURN

The claim most often made for organic fertilizers is that they "do not burn." By burning is meant injury (dehydration) of the roots or crown of the plant, and a browning of part or all of the foliage, sometimes resulting in the death of the entire plant. The tissues are not "burned" as in a bonfire; the burn is a drying-out caused by the withdrawal of water from tissues by the hygroscopic action of "thirsty" chemical materials. Since some manufacturers make a big issue of this "non-burning" quality, many home gardeners have come to regard it as an important factor in selecting a fertilizer product for use.

When anyone makes the claim, "This fertilizer won't burn," my immediate reply is, "Then it won't feed, either." The identical property which makes food elements available as plant nutrients—high solubility—will also make them likely to "burn" or injure plant tissues. The burn may be immediate or it may be delayed, but if the soluble ingredient which causes this condition is present in excess amounts, burn is almost inevitable.

A SOD STORY

On lawns, for example, a burn from an overdose of a chemical fertilizer such as ammonium sulfate becomes visible almost at once, while a too-heavy application of sewerage sludge may not show any ill effects for a month or two after application to the turf. Unfortunately, the burn from organic sources comes so much later after application that it is seldom traced to its cause. Nevertheless, because it happens in summer—a time when grass is peculiarly susceptible to severe injury—a delayed organic nitrogen burn of this kind usually causes more permanent injury than does a burn inflicted early in the season by a chemical fertilizer.

To understand how all this happens let us look at two lawn areas, one fertilized heavily with a highly soluble chemical like ammonium nitrate and the other with sewerage sludge (a typical organic fertilizer). In the first instance, the owner applies 10 pounds of ammonium nitrate in spring soon after grass begins to grow. He fails to water it in, and so the chemical fertilizer begins to suck moisture out of the grass plants to satisfy its "thirst." In a matter of a few days, the entire lawn is dappled brown and green—severe nitrogen burn. After the owner realizes his mistake, he waters heavily to wash out the excess salts; the grass gradually recovers and turns dark green. By June it is healthy and ready for another feeding. This time the owner waters it in and no burn results.

The same week in early spring the second lawn, perhaps next door to the first and on the same type of soil, is fed with sewerage sludge because the owner is convinced this organic fertilizer will not burn. He applies 50 pounds per 1,000 square feet of lawn. April and May remain cool, however, and because soil bacteria are inactive the organic material is not broken down and this first application produces no results. The owner, certain he needs more fertilizer, dumps on another 25 pounds of sludge per 1,000 square feet. The two applications contribute less than four pounds of actual nitrogen per 1,000 square feet, not an excessive amount by any means. If organic nitrogen were really non-burning, he would have no trouble.

Unfortunately for him, the theory doesn't hold water. About the first week in June, hot weather comes on suddenly. Soil bacteria that have been all but dormant begin to multiply at an unbelievable rate. In a matter of two weeks, nitrogen is being released from the sludge-rich soil to the plants so rapidly that grass blades wilt and collapse. If a nitrogen test chemical is applied to the grass at this time, tiny beads of red will show up on every blade. This indicates that free nitrogen is being released—actually exuded from the blades—by a process known as guttation. This lawn is suffering from a far more serious nitrogen burn than lawn number one received in spring. About as close as the second lawn owner will come to knowing the real cause, however, will be his comment, "I guess my grass just couldn't stand summer heat."

Golf course greenskeepers are familiar with this problem. Because they must always maintain grass in top condition, they often have to push turf feeding close to capacity and risk bringing on guttation.

The moment they see traces of grass blade wilting or "flagging" they will apply test chemicals to see if nitrogen is coming out of the foliage. If it is, a crew of men is quickly assigned to wash (leach) the excess plant food out of the soil with liberal applications of water.

AVOID EXCESS

A paramount fact every gardener should fix in mind is that any excess of nitrogen beyond the needs of the plant will cause a burn. This burn may become visible very soon after the fertilizer is applied or, in the case of manures, the effect may be delayed many weeks.

Even certain organic products can cause rapid burn if used in excess. Dried blood, one of the most valuable sources of nutrients, is so readily soluble that it may work like a chemical fertilizer salt. The same is true, to a somewhat lesser degree, of fish emulsions and urine.

BUY BY CONTENT

In the following source lists of fertilizers (and throughout the book) you will note that I almost invariably give technical names and discuss basic fertilizer materials rather than trade-named products. Every ingredient can be found in a variety of trade-named "plant foods." Fancy names and pretty pictures on the fertilizer bag won't feed your plants. Read the legally required label of contents on the bag or box of each brand of fertilizer in the store. Buying according to actual content of ingredients is the only sure way of getting what you want, and need—and pay for.

CHEMICAL SOURCES OF NITROGEN

Ammonia (liquid ammonia): This is perhaps the most widely used of all nitrogen fertilizers today, yet is of no practical value to the home gardener because special apparatus is needed to apply it. It is mentioned here only because many gardeners ask about it after reading accounts of its use in agriculture. These liquids run about 30 per cent ammonia, of which about 85 per cent is nitrogen.

Ammo-Phos (ammonium phosphate): There are two commercial grades of this material. Grade A contains 11 per cent nitrogen and

48 per cent available phosphoric acid. Grade B contains 16 per cent nitrogen and 20 per cent phosphoric acid. Both are excellent sources of completely soluble nitrogen and phosphorus.

Ammonium Phosphate: There are two grades: monoammonium phosphate contains 11 per cent nitrogen and 60 per cent phosphoric acid while diammonium phosphate analyzes at 23 per cent nitrogen and 53 per cent phosphoric acid. Both are completely soluble. Beware of using them on rhododendrons and other acid-loving plants, however, as they are quite alkaline in reaction.

Ammonium Sulfate (sulfate of ammonia): Once the leading source of nitrogen in chemical fertilizers, it is still #1 on the home gardener's list. In the agricultural field its place is being taken over by liquid ammonia. Sulfate of ammonia contains about 20 per cent nitrogen. It can be applied dry but must be watered in immediately to avoid burning. It is much safer if first dissolved in water.

Sodium Nitrate (nitrate of soda): This was one of the first chemicals used as a fertilizer. Vast deposits of sodium, combined with oxygen and nitrogen, were found in Chile, and were worked for fertilizer purposes during the nineteenth century. Because it was for many years the leading source of chemical nitrogen, it is firmly entrenched in the literature of gardening. It is often recommended out of habit when other materials would be safer and better. Sodium nitrate may have some use in strongly acid soils but will deflocculate clays and make them greasy if used too often. It is *not* an ideal source of nitrogen and other materials should be substituted if possible.

Urea: Discovered originally in urine, this is now produced synthetically in large quantities. Urea is not a protein but because it contains a carbon particle, it is classed as an organic compound, to the consternation of organocultists. While not instantly available, urea goes through fewer stages to break down into nitrate form, hence starts feeding a little more rapidly than do organic products.

Ureaform: This is a most unusual fertilizer material—it is best described as a nitrogen-bearing soft plastic material which breaks down slowly but uniformly when in contact with soil organisms and moisture. It is made by reacting urea and formaldehyde. It contains 38 per cent nitrogen, yet can be applied to grass without fear of burning. This is because ureaform gives off nitrogen so slowly that grass can absorb it about as fast as it is released. Enormous quantities have to be applied before a burn can be produced. Ureaforms combine the best features of chemical and organic plant foods. Their one drawback is the slowness with which they begin to feed. (See recommendations under mixed fertilizers for overcoming this weakness.)

ORGANIC SOURCES OF NITROGEN

Any organic material which contains protein can be considered a source of nitrogen, but whether it will be economical to use is another question. A friend of mine once wanted to set up a factory to process garbage for use as fertilizer. In a day's time, I located thirty other waste products for him in his city which would give him a higher return for his efforts than garbage. Many of these products could be had free and all were more pleasant to handle.

Organic products which are high enough in nitrogen to be worth commercial development are not too easy to find. Here is a list of some which are generally available:

Castor Putnace: This is the refuse left after castor beans are processed for oil. It cannot be used for cattle feed because it is poisonous to animals (but not to plants). It contains about 5.5 per cent organic nitrogen. Traces of both phosphorus and potash make it a fair fertilizer, particularly on acid-loving plants.

Cottonseed Meal: Also used as a fertilizer for acid-soil plants, it contains about 6 to 7 per cent nitrogen, 2 per cent phosphorus and 2 per cent potash. Since it can be used for cattle feed, the price is usually too high for general garden fertilizer use.

Dried Blood: Perhaps the most valuable single fertilizer available —organic or inorganic—because it contains in quickly soluble form every element needed by plants for growth. Only the cheaper grades of dried blood (which contain about 9 per cent nitrogen) are used as fertilizers, however, since the better grades are used for industrial purposes and cattle feed and thus command high prices. Fresh blood, sometimes available from local slaughterhouses or from poultry processing plants, can be adsorbed on peat moss, vermiculite or similar materials and used in that state. Nothing gives foliage plants as fine a dark green color as does dried blood.

Fish Emulsions: These fertilizers are produced by soaking trash fish, offal and scraps in water to extract all the solubles. This extract is then condensed until it contains less than 50 per cent water. Surprisingly, the condensed product does not have an offensively fishy odor. The method of extracting insures that all elements are present in soluble form and are readily available to plants. Like dried blood, fish emulsions (they contain considerable blood) provide every element needed for growth. In my experience they are ideal for shade-loving plants like tuberous begonias, gloxinias, African violets, and so on. Fish emulsions have a nitrogen content of about 5 per cent, but they should not be judged solely on nitrogen.

Sewerage Sludge: Perhaps this is the most widely used of all organic fertilizers for lawns. Activated sludge is a black, flocculated organic material produced by treating solids in sewerage and allowing them to settle out in special beds. If the nitrogen content is more than 5 per cent and the analysis shows any amount of potash, the chances are that the sludge has been doctored with additional chemical nitrogen and potash. Activated sludge is a good conditioner for other fertilizers that tend to cake in the bag, hence it is used to a far greater extent than most gardeners realize.

Tankage: This is made up of packing house wastes steamed to extract the animal fats. The remaining tankage contains between 6 and 10 per cent nitrogen.

PHOSPHORUS SOURCES

Bone Meal: This is possibly the most overrated of all fertilizer materials. Beloved by tradition-bound British gardeners, it has been the universal remedy recommended whenever the "authority" was stumped and had to say *something.* I suspect the reason bone meal is so frequently recommended is that since it does nothing to the plant of any importance, it does no harm. In fairly acid soils, for example those with pH readings of from 5.8 to 6.2, phosphorus becomes available if bone meal is used liberally. In soils of higher or lower pH readings, phosphorus locks up in insoluble forms that cannot be used by plants. Where phosphorus is needed, superphosphate will supply it at a fraction of the cost of bone meal, and in much more available form. If bone meal can be had practically for nothing it has some slight value, largely for its small content of nitrogen.

Rock Phosphate: In raw form, just as it is dug from the ground and pulverized, rock phosphate is a fairly good source of slowly available phosphorus. The studious gardener who consults foreign texts should not be deceived, however, by results reported in Europe. Phosphate rock used abroad comes from Africa and is of a different type than American rock. The African product provides much more available phosphorus. Finely ground American phosphate rock, in acid soils, becomes slowly available after the second year. In alkaline soils, it is practically worthless.

Superphosphate: This is *the* basic phosphorus fertilizer. It is a mixture of monocalcium phosphate and calcium sul ate, produced by treating the raw rock with sulfuric acid. The regular grade contains about 20 per cent phosphoric acid, while triple super phosphate may go as high as 48 per cent. Someone has said that without this source of phosphorus, American agriculture would grind to a halt. While this is a bit extravagant, the statement does point up the vital role played by this one material.

POTASSIUM SOURCES

Muriate of Potash: It's odd how this old-fashioned name remains in use! Muriate comes from Muria, the Latin for brine. Muriate of potash is potassium chloride containing between 50 and 60 per cent potash. It was deposited eons ago by ancient seas and should be considered a natural product, blessed by organocultists, but it is not. Its chlorine content passes off rapidly when applied to soil. As explained under soil organisms, however, muriate of potash is harmful to certain beneficial bacteria. Some authorities think sulfate of potash is better.

Sulfate of Potash: This contains 48 per cent potash. It is more expensive than muriate of potash but is considered less harmful to bacteria and plant roots.

Wood Ashes: About the only generally-available organic source of potash, this material is treasured by organic gardeners. Wood ashes contain about 6 per cent potash, plus considerable lime. Before corn cobs were used industrially, the cobs were burned in huge piles. The resultant ashes were peculiarly rich in potash—up to 35 per cent. Almost any ash resulting from burning organic materials that contain some fiber should be a fair source of potash. Wood ashes are particularly good to use for adding potash to a compost heap.

MIXED FERTILIZERS

Most home gardeners prefer to buy their plant nutrients as premixed products—the so-called complete fertilizers (often erroneously called balanced fertilizers). Many years ago, before we knew as much as we do today about plant nutrition, three elements were said to be essential. Although we still know too little about nutrition, we do at least realize that these "Big Three"—nitrogen, phosphorus and potash—by no means supply all elements vital to growth. Nevertheless, any mixed fertilizer containing these three elements may legally be labeled "complete." According to law, at least in most states, such complete fertilizers must contain at least twenty units of plant food. Figures that state how many units are contained in a product must appear on the bag or package, with nitrogen, phosphorus and potash appearing in that order. In one or two southern states, however, the figures for the last two elements are sometimes listed in reverse order.

HOW TO READ THE BAG

So far we have considered the nutrient content of fertilizer materials in percentages. If you want to apply 4 pounds of actual nitrogen to 1,000 square feet of lawn, it is easy to figure that this can be supplied by 100 pounds of a 4 per cent material or 25 pounds of a 16 per cent material.

The problem seems more confusing when mixed fertilizers are used because the bags carry three figures instead of one. However, remember that these are still percentages. Thus a 10-8-6 fertilizer contains 10 pounds of nitrogen (N), eight of phosphorus (P) and six of potash (K) in every 100 pounds of fertilizer.

When I first began using commercial fertilizers, figuring percentages was easy: everything was packed in 100 pound bags. This was hard on the back, of course. We had no handy small cartons, no 50-

or 35-pound bags, but at least we knew, without figuring, that a 100-pound bag of 5-10-5 would supply 5 pounds of nitrogen, 10 of phosphorus and 5 of potash.

Today it takes a wizard to figure out actual weights and percentages. Despite the need for doing a little paper work, the gardener who wants to be careful with his pennies should take time to work out costs.

COST PER POUND

The most important figure is the cost per pound of nitrogen. A product which contains 40 per cent or 40 units of nitrogen and costs $20 per 100 pounds sounds expensive by the pound (50 cents per unit). It would, however, be cheaper than sheep manure which sells for $2.10 for a 50-pound bag but contains only between 1 per cent and 2 per cent nitrogen. Compare the 50 cents per unit cost of nitrogen in the first product with the cost—between $2 and $4—of each nitrogen unit in the second product, sheep manure.

Another way to figure costs is by the total plant food in a product. A dried sheep manure, for example, that contains 2-1-1 units of the "big three" nutrients, usually sells for $2.10 for a 50-pound bag; this sounds cheap, yet the cost per nutrient unit is over $1. A mixed ureaform fertilizer analyzing at 20-5-5 and selling for $9.95 for a 50-pound bag would at first glance seem many times costlier, yet the cost for all the units is less than 67 cents per unit.

In figuring fertilizer costs you should give some thought to the form in which the plant food occurs. While urea would be cheaper on a cost-per-unit basis, it is inferior to ureaform as a long-lasting turf fertilizer that provides an eight-month feeding period and greater safety in application.

RATES OF FEEDING

A great deal of fuss is made about the feeding value of various fertilizer formulae. I have seen amateur rose growers, for example, all but come to blows in arguing whether a 6-1Q-7 was a better rose fertilizer than a 5-10-5 or a 4-12-4. Advocates of all three were vehement in their protests that only their ratios and rates of feeding would produce perfect roses.

I wish I could be that dogmatic with any degree of confidence in my recommendations. Where I can be dogmatic is in saying that there is no perfect general formula. Within reason, any complete fertilizer will produce good roses and other plants if the grower uses enough, without going overboard. Soil is an amazing buffering agent and will accept many times the amount of fertilizer usually recommended—without injury to the plants. I recall a vegetable garden I made early in World War II. As a member and officer of the Illinois State Victory Garden committee, I was on the go night after night and had little time to do my own work. Yet I felt that I should set a good example and make a home vegetable garden. The only answer was to have the soil preparation and fertilizing done for me. The handy man I hired was not too good at figures (particularly decimals) and skipped a place in his calculations, which resulted in the application of ten times as much 10-6-4 fertilizer as I had intended.

Fortunately, this was a complete fertilizer, not only in the big three of N, P, and K, but in the minor elements as well. To show how selective and discriminating plants are in their food uptake, I saw not one instance of over-feeding of any one element. True, the weed growth was phenomenal (this was the first time in my life I ever had to cut ragweed with an *axe)* but everything else grew on the same phenomenal scale. *So long as food elements are in balance and are supplied in amounts sufficient for good growth, with no one ingredient lacking, plants can be depended upon to take what they need and leave the surplus unused.*

This does not mean that the point cannot be reached where the soil will be saturated with excess soluble salts which will damage or kill the plants. It does mean that the soil, particularly when it is liberally supplied with organic matter, is capable of buffering tremendous overdoses, so that, within reason, an accidental overdose need not be a calamity.

TAKE YOUR CHOICE

You may think I am inconsistent in recommending that formulae be checked carefully to see that plant food units are being purchased at the lowest cost, then stating that not too much attention need be paid to the value of one formulae over another, providing they are reasonably similar in analysis and seem suited to the use to be made of them. My reasoning is, however, sound.

In order to determine exactly which of two or more fertilizer formulae would better meet the needs of the flowers, vegetables, shrubs or fruits growing in the garden, you would have to: (1) make expensive soil analyses at intervals during the growing season, to see what is left from the nutrients you applied, and (2) run experiments to see whether variations in the fertilizer formulae would produce superior results at lower costs. In the end, all this bother might save you a dollar or two a year, but this saving would be offset several times over by the cost of the soil analysis. I feel that soil tests for gardening is like swallowing a camel but straining at a gnat.

Of course, the technically minded gardener who enjoys dotting his Is and crossing his Ts can't fully enjoy himself without soil tests. I just don't feel they are necessary or desirable for the "average" home gardener.

Incidentally, a generally overlooked point concerning organic fertilizers (other than urea or urea-form products) is their content of insoluble nitrogen. Unless all or almost all of the nitrogen in any organic product is insoluble in water, the product will not give the "slow-release" or slowly available nitrogen effect for which you purchased and applied it. Here, again, is a dandy reason for checking package labels—including the tiny print—before you buy.

CHAPTER DIGEST

The ideal fertilizer—one that is all things to all plants—probably never will be produced, either by nature or by science. But there are many chemical and organic fertilizer source materials which supply nutrients that will do a good job if properly used, especially in mixtures. The discussion of nitrogen fertilizer "burn" should clarify—and eliminate—the problem for all gardeners. Similarly helpful are the explanations of specific fertilizer elements, how plants utilize them, the meaning of the three numbers on a fertilizer bag, and ways to figure fertilizer costs.

Chapter 6

(not vs.) Organic and Inorganic Gardening

PERHAPS the greatest controversy in the gardening field during the past two decades has enveloped the relative merits of chemical nutrients and organic nutrients. The arguments have been so confusing for gardeners—even for those who are scientifically trained—that a thorough discussion of both "organic" and "inorganic" viewpoints is indispensable to any consideration of soils.

Most experienced plantsmen and soil specialists today occupy a middle ground, using organic and chemical materials as seems best suited to the needs of a particular soil, plant, or circumstance. But those who are at the extremes—violently pro-organic or anti-organic—press their arguments so vehemently as to almost drown out the moderates. The logical way to resolve this argument is to try to state both sides clearly and allow facts to speak for themselves.

Primitive man knew nothing about feeding plants. He simply and without awareness relied entirely upon native fertility or upon natural replacement of fertility for all of his crops. When a field became unproductive he merely moved on to fresh land. Nature's bounty was accepted without thought of how, what, or why. This approach, in basically the same form, continued through the centuries. The Greeks, Romans and those who came after them made some progress in plant feeding, with all of it based on natural manures and similar organic materials.

As the years passed, growers showed an increasing awareness of the need for replenishing the soil—restoring food elements that plants removed. It was not, however, until the experiments of Justus von Liebig (1803-1873) that man really began to break away from dependence on natural manures. Liebig's discoveries came at a fortunate time for the human race, since new naturally fertile land for crops and pastures was running out.

EARLY CHEMICAL FERTILIZERS

Discovery of phosphorus and superphosphate as plant nutrients (one of the great scientific highlights of the nineteenth century) plus investigations of nitrogen, potash and other elements, resulted directly from von Liebig's work.

A fundamental error in much of the thinking of his day (and one which persists even today) was in considering soil as a bank into which deposits of fertilizer could be made and withdrawn at will. No account was taken of the role of soil organisms, the vital nature of humus, the self-regenerating capacity of soils and the need for replacing certain elements not yet proved essential to plant growth.

Because use of certain chemical elements resulted in large increases in crop yields, demand for these elements in even higher purities became so insistent that fertilizer manufacturers devoted more and more of their research and production to satisfying this demand. When these higher-analysis products became widely available, however, a point of diminishing returns was reached. Plants actually showed signs of doing less well when fed with these "pure" chemicals than when fertilized with natural manures or with fertilizers of lower purities.

Today, we realize that plant nutrition is a far more complex process than merely supplying the so-called "essential" elements of nitrogen, potash and phosphorus. We know now that plants fed with highly purified forms of plant food are not poisoned by some toxic substance. True, the plants look sick and are subject to disease and insect attacks because they lack vigor. If, however, those elements which are eliminated in purification processes are restored, growth will quite possibly be superior to that produced with even the richest organic manures.

Here it is important to make one point: the existence of a true toxic commercial fertilizer element that will poison plants and can be passed on to animals and man has never been demonstrated. Of course, there *are* chemicals which, if supplied to the soil in excess, will cause injury to plants, yet these same chemicals may be needed in small amounts for normal growth, whether derived from mineral (chemical) or organic sources.

Also there *are* powerful chemicals such as selenium which are absorbed by plants and can poison man, but these are carefully extracted from chemical fertilizers in manufacturing. Such poisonous elements are much more likely to occur in natural plant foods than in chemicals.

RISE OF ORGANOCULTISM

Time passed and chemical fertilizers became the standard. Then, about thirty years ago, the philosophy of a feeding program based on pure chemicals received the challenge that started the controversy we have today. It came from Sir Albert Howard, of England, who was born a Shropshire farm boy, but moved to the West Indies as a young man. Later, in India and Africa, where he moved to preach his ideas of plant nutrition, he worked to perfect a theory that humus and compost alone were enough for healthy plant growth, and that chemicals interfered with natural processes.

Unlike many of his followers, both of the past and today, Sir Albert was a man of solid scientific background. An honor graduate of Cambridge University in England, he was a competent mycologist, trained in scientific methods and observation. Many conclusions he drew from his experiences in India were sound, but not necessarily all-inclusive. His bias in favor of organic matter was a natural result of the climates in which he worked. In the tropics, loss of humus and other organic matter from soil goes on at all times, night and day, winter and summer alike. Never during the entire year's cycle do soil temperatures drop low enough to keep avid bacteria and fungi from attacking every scrap of organic matter that falls to earth.

Liberally watered by rainfall (which further favors soil microorganisms), India's soils are all but devoid of humus. Also, with as much as 300 inches of rain in a single year, no soluble chemical remains available for more than a day or two at the most. In one test, Sir Albert applied composted organic materials to soils. The result was a phenomenal increase in yields, as was to be expected, because of the longer life of organic matter in the soil. Such results could not possibly be duplicated by use of pure chemicals under East Indian conditions, since as much as a pound of nitrogen in soluble form applied to 1,000 square feet of soil could be washed below the root zone of garden plants almost overnight.

A strong case against the superiority which Sir Albert claimed for organic plant foods in tropical climates was offered by the soilless culture used successfully on tropical islands during World War II. Because of the lack of true soil on many of these islands, vegetables were grown in tanks containing all necessary nutrients in soluble form. Production was much higher per square foot than in soil. Nutritionally, the nutrient culture vegetables were ranked as equal to the best.

Toward the end of his life, Sir Albert moved back to England and continued to preach his gospel of organic gardening. Out of this has come a cult of organoculture which holds certain vague tenets but fails to clearly define these to the satisfaction of most scientists. Because the organocultist credo is not stated in words that can be answered with simple scientific evidence, perhaps the best way to give the story is to sum up and analyze a few of the many discussions I have had with various proponents of the all-organic theory.

THE CASE AGAINST ORGANIC GARDENING

The question is not whether organic matter is good or bad. Almost any individual who has worked with soils will agree that organic material is a basic ingredient of gardening. If I were planting a 40-foot oak at this moment, you may be sure that all the well-rotted manure or compost I could afford would be mixed with the soil around the ball of earth, and that there would be at least 6 inches of organic matter in the bottom of the hole. In making a lawn or vegetable garden I would prefer to work into the soil a layer of at least 3 inches of organic matter. All through this book you will find recommendations for the liberal use of organic matter. If anyone wants to make me a present of a load of manure, I would welcome it as much as any other thing I know. In short, I believe in organic matter.

My argument, then, is not with those who think natural sources of plant nutrients are good but with those who are turning otherwise normal human beings into superstitious, frightened faddists who see a death's head in every ordinary grocery store cabbage. These faddists, in their terror of a mysterious "something" in chemical fertilizers, are spoiling the fun of gardening (and eating) for everyone. This cult holds that continued use of chemical fertilizers (or chemical insecticides and fungicides too, for that matter), particularly on edible plants, is dangerous and should be barred by law. It further holds that recommendations by recognized authorities for the use of such chemicals is an organized plot by commercial firms to profit from the poisoning of men, women, and children.

This cult further states that all needs of plants for elements essential to growth and life can be met from natural organic wastes without fortifying or supplementing such natural fertilizers with chemicals. Within this cult we find an amazing assortment of individuals. A few of them are outright liars. Some are self-seeking opportunists doing exactly what they accuse commercial fertilizer manufacturers of doing—profiting from the sale of a spurious product.

Most of them, however, seem to be decent, honest folk, self-deluded, but looking for right answers to life's problems, except that they are looking down the cellar steps instead of out the window. From various sources they have accumulated strange, unproved theories about the way plants grow, what they need and how these needs can be supplied. These theories are phrased in vague, pseudo-scientific language which does not follow ordinary principles of plant physiology.

WHAT IS ORGANIC?

My first difficulty in opposing these organocultists arises in trying to define what they mean by organic. To a chemist, any product is organic if it contains a carbon particle or radicle. This includes urea, which was originally discovered in urine, but was later produced synthetically. If urea is separated from urine it cannot be distinguished in any way from the same chemical produced synthetically. The organocultist, however, accepts urine but rejects urea because it is not a pure organic product.

Obviously, then, the organocultist does not use the word organic in its true scientific sense—that of chemical structure. Perhaps he insists that for a substance to be usable, it must exist in a living organism or have been derived from such an organism. Here I foresee even more difficulties. To illustrate, let us fertilize a pasture with purely chemical nitrogen, such as ammonium sulfate, then allow steers to feed on the grass and return their wastes to the soil. Does the nitrogen in these wastes become pure and organic? Does beef scrap from the meat of these cattle change from inorganic to organic form?

If, however, in the process of decay, some of the contained nitrogen is set free in the atmosphere and is later fixed electrically at a power plant such as Muscle Shoals, will it still be organic—or inorganic? How can a molecule of "organic" nitrogen be distinguished from one that is purely "inorganic"?

Next let us examine fixation of nitrogen from the atmosphere. The most avid proponent of natural products could not object to nitrogen fixed as an oxide by lightning in the atmosphere. This is certainly as "natural" a product as one could imagine. Yet no man in his right mind would argue that air is organic unless he happened to be riding in the New York subway in rush hour. Even clovers when they extract nitrogen with the help of bacteria must absorb a product which was originally pure nitrogen gas, without a particle of carbon in it—definitely a chemical in every way. When, however, this nitrogen is converted into protein by clover plants, the original particle is there, unchanged in any way. At what point is the changeover made? Does combination with sulfur and half a dozen other chemicals, plus the process of growth, make the nitrogen any better or change the nature of its molecule? Unless organocultists can prove plants split atoms and recombine elements in new forms, they must logically admit that one nitrogen product is an exact duplicate of another.

COMPLEX POINT

About the only consistent point with organocultists is that they seem to prefer complex materials rather than simple, uninvolved combinations of only two or three chemicals. Is it because plant wastes are more complex in structure that they are superior to ammonium nitrate, for example? There is one grain of truth here that bears discussion. Because it is complex, such an organic waste substance might be more complete and contain one or more elements not included in a chemical plant food. At the same time it cannot be denied that every element found in organic matter can also be supplied in mineral or chemical form; indeed, as we know, plants are incapable of absorbing the nutrients in the original complex form.

If complexity is part of their credo and complex substances are necessarily better than simple ones, how then do organocultists explain water? Here is a simple chemical—a combination of two atoms of hydrogen with one of oxygen, without which life would be impossible. Yet surely the most avid organic proponent would not dare to call water organic.

What about limestone? We are told that good old ground limestone rock is wonderful stuff—a natural "fertilizer." If, however, we expose that same rock to the action of fire, the product is a vile chemical which must not be allowed to touch soil. Does this add to the logic of the organocultist argument?

Just about as unconvincing are the arguments advanced in favor of phosphate rock against superphospate made from this same rock. Superphosphate, they insist, is horrid stuff. It has been treated with sulfuric acid to make it more available to plants, but this treatment is supposed to make it a "poison." But how in the name of logic does the organocultist think phosphate rock becomes available if not through dissolution by natural sulfuric acid in the soil? If not dissolved in this way it can remain unchanged for thousands of years, completely unavailable to plants.

SCIENTIFIC REBUTTAL IS DIFFICULT

Unfortunately, facts never seem to bother many organocultists. Defeat one argument with scientific evidence and they will bob up with half a dozen more, each requiring the equivalent of a master's thesis to refute fully. In trying to answer some of these arguments, I often feel like Hercules fighting the Hydra. Cut off one head and two more grow in its place. Or as one scientist phrased it, "I feel as though I am punching a bag of wind that merely distends in another direction every time I jab it."

The honest scientist is at a disadvantage in answering vague arguments. To give a satisfactory answer would involve giving elementary courses in organic and inorganic chemistry, colloidal chemistry, the theory of pH and ionic exchange, bacteriology, entomology, nematodology, plant physiology, and half a dozen equally complex and time-consuming fields of study. To give you something of an idea of the type of argument that must be refuted, take a friend of mine, who is certain that his wife's recovery from "arthritis" is proof of the validity of organic gardening. He presents this "history" in evidence:

Because she had what he called "arthritis," they moved to Florida. She began to eat organically-grown vegetables and her arthritis disappeared. He is perfectly sincere in insisting this proves organic gardening can cure disease. Frankly, this is about as poor a case of proof as I have ever heard presented. First, any true scientist would insist that instead of one woman, he would want at least 100, as much alike in age, race, general cultural background and habits as possible. They would all have to be married to my organic-gardening friend. What's more, he would have to treat them all alike. No fudging—each one would have to dress alike and eat a normal diet full of despicable chemically-grown food.

The next step would be to inoculate half of these women with arthritis in some way. Since we do not really know what causes arthritis (in spite of the claims of organocultists) this would be difficult to do. The other 50 women would serve as a control by remaining on their "chemical" diet. The experiment would have to be continued over several years to be sure results would be statistically significant. During this period, SO arthritic women would have to be fed a diet grown organically—compost-fed potatoes, manured cabbages and what not. After a specified length of treatment, it would not be enough to have one or two of the subjects recover from arthritis. Unless most of them were cured the experiment would be rated as non-conclusive.

Such an experiment is obviously impossible, but I felt that stating it in some detail would show up the vagueness of what organic gardeners offer as proof.

THE CHINK IN THE ARMOR

There is one major weak spot in the organocultists' armor. It is their habit of citing authority, often out of context and often without fully understanding what they are quoting. I feel it is only fair that if they quote a certain individual as an authority on gardening, they accept his views on that subject. They don't have to recognize him as an authority on love, politics, the Einsteinian theories or the atom bomb, but they *are* stuck with him on gardening.

With this in mind, I wrote to half a dozen acknowledged authorities on gardening whose writings have been quoted from time to time by organic-gardening publications. I asked these experts for their opinions on five specific questions:

1. Do you think chemical fertilizers cause damage to plants or cause plants to grow abnormally?
2. Do you think plants fertilized with chemicals rather than pure organics are more subject to insect attacks?
3. Are plants fertilized with chemicals more subject to plant diseases?
4. Are organically-fed plants better protected against insect at tack and diseases?
5. Do you think that eating chemically fed plants will cause cancer, arthritis and poor teeth?

Out of the six expert gardeners contacted, all replied with a flat No to all five questions. In addition, the American Medical Association, which disqualified itself on the first four questions, emphatically denied that plants fed with chemical fertilizers could be proved to cause cancer, arthritis or poor teeth.

One reply was from Harry O'Brien, whose national magazine column, "Diary of a Plain Dirt Gardener," was read by millions every month. His answers were typical. He said:

"(1) Chemical fertilizers used according to accepted standards are not dangerous to plants and do not cause abnormal growth.

(2) Chemical fertilizers do not make plants more susceptible to attack by insects. In fact, they do just the opposite. The well-fed, thrifty plant is less susceptible to attack.
(3) This is even more true of plant diseases. Well-nourished plants almost invariably withstand disease better.
(4) I do not think feeding plants organic fertilizers keeps insects from attacking them. I just don't believe it.
(5) The fellows who say that plants grown with chemicals will, if eaten, cause cancer, arthritis and poor teeth are just exposing their ignorance."

Some years ago I made a speech before a convention of the Men's Garden Clubs of America. In that talk, I warned the audience against careless and off-hand use of insecticides such as DDT. (I would say the same things about aminotriazole today.) I made no plea for prohibition of such chemicals but merely urged care in following the package directions when using any insecticide. This speech was quoted in one of the organocultists* journals. Since the organocultists thus have recognized me as an authority, I feel I am entitled to express my views of what they claim:

CREDO

I believe that the whole "all-organic" movement is inspired by blind, unthinking prejudices. I know that sound, healthy plants can be grown with chemical fertilizers and that human beings can eat them with safety, benefit and pleasure. I feel it is up to organocultists to name, in terms intelligible to sane people, just what elements exist in chemically-fertilized plants that make them harmful, or what beneficial elements occur in organically-grown plants and not in those grown with mineral fertilizers.

I believe that man's knowledge of gardening, farming and the application of new scientific discoveries has been set back half a century by the pseudo-scientific pronouncements of the organocultists.

I take the stand that we who advocate the use of chemicals and organic matter do not have to prove our case: the shoe is on the other foot. It is the organocultist who must prove *his* anti-chemicals case by presenting evidence that will stand up when submitted to scrutiny by intelligent, knowledgeable men and women.

Among the familiar pieces of "evidence" used by the proponents of organic fertilizing are the figures from State and Federal sources that show a steady increase in the number of deaths from heart disease and cancer. Here, they say, is positive, irrefutable proof that chemical fertilizers are killing us. The actual death figures, of course, are accurate. But the way organocultists use the statistics reminds me of the time I "proved" statistically that a decline for a certain period in the American birthrate was due to increased sales of electrical refrigerators because, on the chart, one curve dropped at the same rate that the other climbed. Arguments that chemical fertilizers cause disease are about as valid. The government's death figures are accurate but the organocultists' interpretation is not.

What is actually happening is that we are saving more young people and extending the life span of the middle-aged and older people so that everyone lives longer, only to succumb to degenerative diseases such as heart failure and cancer which otherwise might never have been able to attack. Federal figures on median age at death are convincing proof that a false use is being made of vital statistics. If the organocultist-type of logic is permissible, are not advocates of chemical fertilizers justified in claiming that striking declines in deaths from smallpox and pneumonia are due to increased use of non-organic (chemical) plant foods? Imagine the poor gardener, faced with extravagant claims of organocultists on one hand and an advertisement on the other which reads, "Why die of pneumonia? Grow cabbage with ammonium sulfate and live!"

There is an amusing side to the organic gardening cult's refusal to recognize the identical nature of elements in chemical and organic plant nutrients. I have in my file a card that offers me FREE, as a bonus for subscription to a venerable organoculture journal, A SOIL TEST KIT! Presumably this test kit includes the usual chemical reagents (at least I have not heard of any kits that use organic reagents). Since such simple kits cannot differentiate between chemical and organic elements, I am afraid the editors have made a horrible admission.

WHAT CAUSED THE ORIGINAL ERROR?

Anyone who has given any thought to the conflicting claims in this controversy must have tried to figure out what happened to Sir Albert Howard's powers of observation. I am going to venture a guess. What probably set Sir Albert thinking was his observation of the effects of sodium nitrate on soils. Nitrate of soda, as it is called in the trade, was and is a favorite source of nitrogen among British gardeners. It produces effects that might well support claims made against *all* chemicals.

When used regularly on clay soils, this chemical causes almost immediate deflocculation of the clay. That is, the electrical charges holding clay to lime particles are neutralized and sodium carbonate is formed. The result is a greasy, hard-to-work soil which closely matches the organocultists' dark pictures of chemically-fed gardens. So, if you *must* use nitrate of soda, do so never oftener than once a year. Better yet, use ammonium nitrate which leaves no harmful residue.

Sodium carbonate is another material that in excess is quite toxic to plants and causes effects which seem to support organic gardening claims. Another such material is potassium chloride (muriate of potash). This chemical kills certain kinds of bacteria that are able to fix nitrogen from the air. Destruction of these beneficial organisms could degrade the soil to a point where effects would be harmful. Here an organic source of potash—wood ashes------would do a better job than muriate of potash. However, the other garden form of potash, sulfate of potash, will also provide the needed element without destroying helpful bacteria.

Ferrous ammonium sulfate, or FA.S. as it is called, is a valuable material for producing a quick green color on a sickly lawn (a good trick to use when you want a quick treatment to put a lawn in top-notch condition for some special event). However, FA.S. is known to be harmful to a number of soil organisms if watered into the soil or compost pile. For this reason, it is best used as a foliar application on grass, as a light spray. Do not use so much that it drips freely and runs onto the soil.

Danger from F.A.S., however, is lessened if the soil is well aerated.

In dense, tight, waterlogged soils, ferrous ammonium sulfate stimulates bacteria that produce hydrogen sulfide, a chemical harmful to garden plants.

* ♦ ♦

CHAPTER DIGEST

Whenever you think of organic/inorganic gardening, be sure to use "and" and not "vs" between the two words. Organic gardening "prohibits" the use of chemical fertilizers, insecticides, etc. Inorganic gardening, in its strict sense, employs only chemical materials. But actually, "inorganic gardener" is a term invented to identify one who is not wedded to organics. Both kinds of fertilizer, in particular, are vital to a balanced soil that can properly support plant growth.

The organocultists have performed a good service in calling attention to the waste of natural sources of fertility, to the vital nature of organic matter in good soil condition, and to many other phases of culture which were being forgotten in the mad modern rush for high production with chemical fertilizers. But these contributions are spoiled by the organocultists' refusal to see any side but their own. If science and common logic mean anything, the organocultists will never prove the existence in organic matter of any vital ingredient for plant growth which cannot be supplied chemically, or demonstrate the existence of a pure toxic element in chemicals that is not present in organic materials.

Chapter 7

Organic Matter in Soils

FROM the time plants first ventured out of the protecting waters of the sea, there has existed a kinship of soil, organic matter and plant life which has continued down through the ages. Even before the first feeble formation of land began, the processes of soil development were well under way. For millions of years, mineral elements had been accumulating: sand and gravel flaked away from rocks high in silicates; wind, water and frost disintegrated various oxides into clay, and sedimentary layers lifted above the seabed and gave up their lime.

These accumulations of rock debris were not, however, true soils. Plants, microorganisms and organic matter—life elements that had not yet appeared on dry land—were necessary for the formation of true soils.

No fossils remain today to give us a picture of the first "plants" that crept slowly out of the waves and onto the rock. Soft, without skeletal structure or fiber, these plant forms left behind no clue of how they were able to escape their dependence upon the sea. Eon after eon must have passed before one form less fragile than the rest was at last able to leave the protecting waters and establish itself permanently on dry land.

FOOTPRINTS ON THE SANDS OF TIME

From here on, the record is easier to read, since the descendants of these primordial bits of vegetation still cling to the rocks at the ocean's edge—the lichens that grow much as their ancestors did millions of years ago. Primitive in structure and function, they ask little of their environment. Their life-cycle helps to form soil today just as it did then. Since lichens have no roots, they have no need for soil. Instead, their hold-fasts cleave to the naked rock, emitting an acid that dissolves the stone beneath them, releasing solutions of minerals on which they live. Some of the rock resists dissolution, leaving harder grains that tumble down the slope to collect in hollows at the base. The lichens themselves die, crumble to dust and join the mineral build-up at the base. Fungi and bacteria invade to feed upon this pile of mineral and plant matter, and thus does the world's stock of soil increase.

In the course of checking various reference works and subject-index-files, I noted nearly 850 different phases of organic matter and their relation to soils and plants. Many of these phases would easily occupy a full chapter, while others could not be adequately treated in anything less than a full-length book.

For example, there is humus, an important end product of organic matter in soil. In 1935, Dr. Selman A. Waksman, of Rutgers University, the noted microbiologist who developed some of our most effective antibiotics, wrote a book entirely on humus and its relation to soil. It is one of the most exhaustive studies of a soil fraction in existence, yet in the end it leaves unanswered as many questions as it answers. (Anyone who thinks soil organic matter is a simple subject should read Dr. Waksman's book, published by Williams and Wilkins Co., Baltimore, Md.)

The recycling of organic matter, using and reusing basic elements over and over to keep unbroken the chain of existence on earth, is vital to all life. Were it not for death and decay, all the carbon and nitrogen in the world would soon be locked up in permanent form in bodies of dead plants, animals and men.

TYPICAL PATTERN

Let us follow a plant in the garden as it dies and falls to the ground in late fall. In spring, the gardener digs it into the soil; the dead plant (what's left of it) then begins the process of changing to organic matter and humus. *The words "organic matter" are used here in a special sense—the dead remains of plants and animals.* Tissues of the plant that has just been plowed under are largely water—between 75 and 85 per cent in most garden vegetables. Of minerals other than water, about 10 per cent will be carbon and another 10 per cent oxygen (in compounds other than water), plus about 2 per cent hydrogen and 2 per cent ash.

What is particularly striking about the mineral makeup of organic matter is that only 2 per cent of the total of the fresh plant—the ash—is derived from soil. The rest of the plant is made up of elements from air and water. Even the nitrogen, a vital part of the total, small as it is percentagewise, came originally from the air. This emphasizes the importance of air and water relationships (see Chapter Eleven).

By the time our dead plant is plowed under, it has lost much of its water but because winter temperatures are low, bacteria and fungi have not yet been able to attack the solid matter it contains. As soon as soil temperatures go above 60 degrees F. for several days, bacteria and fungi will become active. Their first attacks will be on the starches and sugars in the plant tissues—energy foods they need for continued activity. They will also go to work on proteins, which they need for cell growth.

FAST AND SLOW

Cellulose (the fibrous plant substance that forms the cotton and flax of commerce, for example) decays more readily than do waxes, fats and lignin, but cellulose is more resistant than protein, starches and sugars. The more readily decomposed substances break down quickly into alcohols, aldehydes, amides, amino acids and similar products.

The starches and sugars are almost immediately absorbed by soil bacteria and fungi and used as energy foods. Since these plant forms do not produce chlorophyll, they must get these energy foods from an outside source.

At this stage of breakdown, some humus is formed by an interesting process. Protein is attacked at the same time as starches and sugars but because a more elaborate breakdown process is required for it, there will be some free protein in the soil solution along with lignin. These two substances have a strong attraction for each other and will combine to form humus long before it would otherwise be produced in the end stages of organic breakdown. Any protein which does not combine at this stage will go to feed bacteria and fungi, except for the portion that rotifers, protozoa and other animal forms manage to steal from them.

Cellulose next breaks down, releasing hydrogen, carbon dioxide and methane as by-products. Only two species of bacteria are known to decompose cellulose, both of which are slowed up by acid (low pH) soil. *One reason why adding lime to compost (raising the pH) speeds up decomposition is that the cellulose bacteria are stimulated.* However, too high pH is just as bad as too low.

VARIABLE METHANE

The mention of methane in garden soils may seem strange, since it is a gas usually associated with marshy lands and swampy areas. Actually, while methane is called marsh gas, it is released by many forms of microorganisms that work on carbohydrates, organic acids and proteins. However, in normal soils, it is used as a source of energy by both bacteria and fungi and so does not reach the atmosphere. In swamps, lack of air in the soil favors anaerobic forms of microorganisms that work in the absence of oxygen and do not utilize methane for energy, allowing it to escape into the atmosphere unchanged.

By this time, many series of chemical compounds are in the soil from the tissues of our plant. In addition to those already mentioned, there are sulfates, phosphates, calcium compounds and others. With all of these being released, and processes by the dozens proceeding simultaneously, a seething ferment of infinite complexity results and tremendous amounts of energy are being used. Someone has called organic matter the fuel for bacterial fires in the soil—certainly an apt metaphor.

Organic material containing a great deal of lignin, such as sawdust or wood shavings, presents a problem because usually its starch content is either limited or unavailable, and if nitrogen is supplied in large amounts, the lignin-protein conversion to humus is heavy. *For this reason, sawdust and other woody fibers do not become available readily and should be considered as long-time amendments to the soil.* Eventually the humus does break down, of course, but most gardeners are too impatient to wait for this effect.

OILS FOR HUMUS

Our plant originally plowed under has now released most of its elements to the soil. However, except for the lignin-protein, true humus formation has yet to take place. A major source of humus, surprisingly enough, is a portion of plant materials—fats, waxes, oils and resins—so often mentioned in British gardening literature as likely to ruin a compost pile. I was once told by a farmer that he wouldn't dare spread spoiled shell corn on his fields to rot because corn grain was so oily it would ruin his soil.

Like so many traditional but false ideas in agriculture and gardening, this notion was accepted without question. I believed it up to about twenty years ago, until one day I was lunching with Dr. Emil Truog, the very able head of the soils department at the University of Wisconsin. I mentioned I had thrown away some oil-soaked sawdust rather than add it to my compost pile. His only remark was "Why?" In the discussion that followed, I learned that here we are dealing with a half-truth—an observation not carried to a logical conclusion. It is true that as we watch dissolution of organic matter in a compost pile we do find that waxes, fats and resins are still intact at the end of the first year. It is, however, this very resistance to decay which makes them ideal elements in humus formation.

This does not mean the perfect compost pile is one made up of candles, rancid lard and spent crank-case oil. A pile composed entirely of fatty materials would never get started on decomposition. It does mean that we should not avoid including some oil, fatty or waxy wastes in making compost piles.

A point worth restating here is that all soil processes involve living organisms. When we attempt to study them by chemical analyses, the bacteria and fungi (even if not killed) are no longer in their normal environment. Thus tests are inaccurate. It is not surprising, therefore, to find the careful soil scientist using words such as "I feel that . . . ," "possibly," or "probably," far more often than positive, dogmatic words about the action and nature of organic matter.

SOIL CONDITIONING

During the first weeks following the introduction of chemical soil conditioners, I often made a statement to the effect that "Five dollars spent on organic matter will do your soil far more good than $50.00 spent on chemical conditioners." At that time, these chemicals were being touted as "permanent amendments and conditioners." Today, we know that they have a life of about three years in soils that are worked annually. If I were making that statement today, I would change the latter figure to $100.

In contrast to the three-year life for chemicals, barnyard manures have shown both soil conditioning and fertilizing effects for as long as 50 to 60 years following application.

Organic matter is a soil conditioner which can be matched by no other material. When it can be had practically free, as it can from the home compost pile, it is sheer folly to let it go to waste. Humus is a storehouse for plant "foods" and (along with absorption by bacteria and fungi) prevents the loss of nutrients if they are not used by plants immediately. The extent of these nutrient reserves can be enormous, as in the case of rich prairie soils of the Middle West, many of which continued to produce crops for half a century after they were broken by the plow, often without the addition of any outside source of fertility. While such soil depletion is to be condemned, the case mentioned does show the extent to which soil rich in humus can build up stores of plant nutrients.

In addition to this function, *humus also makes a soil more porous* so that air and water move freely. Humus-rich soil turns easily under the plow or spade and does not pack readily. There is a special "feel" to such gardener's loam which the true gardener learns to know.

One of the most valuable functions served by organic matter is in providing favorable living conditions for bacteria, fungi and other microorganisms. When soil is examined under the microscope, the bacteria will be found clustered around nodes of decaying vegetation or clinging to crumbs of humus. Here they find the food, moisture and air they must have to maintain life and carry on their soil-improving functions.

One of the first steps in improving problem soils such as sands and heavy clays is to mix in plenty of organic matter and thus build up the population of microorganisms. Whether this applied material is compost, rotted manure, spent mushroom manure or dried sheep manure bought in bags from the garden center, it will help "seed" the soil with essential bacteria at the same time that it creates an environment in which they can thrive.

* * *

CHAPTER DIGEST

Organic matter is the "intermediary" that keeps all soil functions in harmony. It is made up of dead plant and animal tissues (plus minerals), and provides, in turn, the essential environment for the growth of plants that give food and pleasure to man. The ideal soil, "Gardener's Loam," is basically one that is high in organic content. The processes involved in the production of humus are complex, but the gardener's chief concern is with how to use the humus.

Chapter 8

Composting and Soil Conditioning

THE compost pile or heap is the time-honored place for all orgam'c refuse, the real gardener's source of humus for incorporation into the soil. The important thing to remember about composting is that it is a biological process, one that involves bacteria, fungi and other soil organisms. These organisms require food to do their work, which means you must supply the same elements that are needed by higher plants. The one difference is that these organisms do not have chlorophyll and are not able to manufacture their own energy foods such as sugars and starches. They draw upon the organic matter for these foods, but in doing so use up large amounts of nitrogen, some phosphorus and potash and small amounts of other elements. For this reason, the application of fertilizers to the compost pile will allow the organisms to work at their best, provided temperatures are favorable for their growth and the pile is moist, without being so wet that air is excluded.

Any form of organic matter that will decay can be composted. Some materials, such as peat moss, spent mushroom manure, spent hops and well-rotted manure, are already partially broken down. These can be applied directly to the soil. However, if a substance contains no cellulose, fiber or lignin, it will not produce humus. Dried blood, perhaps the most valuable of organic fertilizers, is all but worthless as a source of humus, since it contains practically no fibrous material. Urine, a valuable source of nitrogen, urea and other fertilizer elements, is another organic substance which produces little or no humus. Fish emulsion fertilizer is another non-fibrous organic material that leaves very little residue for humus formation. This does not mean they are worthless: on the contrary these three materials are among the most valuable foods for the bacteria that work on compost. A little of any one of these will start the pile or get it working again whenever it begins to slow up.

WHERE AND HOW

The compost heap should be in light shade, on level and well-drained ground. If in full sun, the pile may heat up enough to kill bacteria near the surface. Considerable heat is developed in the composting process itself. In dry regions, the pile might well be made in a shallow depression to catch rainfall, but this basin should not be so deep as to risk "drowning" the lower layer of compost.

Unless the soil in the pile site is naturally high in lime, sprinkle the area with ground limestone before applying the first layer. Each successive added layer should also be sprinkled with limestone: the processes of decay generate acids which will slow up bacteria while favoring fungi. If this happens the nitrogen products left behind will be ammonia nitrogen rather than the more desirable nitrate nitrogen forms. The addition of lime favors bacteria rather than fungi.

Build the pile like a giant sandwich of 4-inch alternate layers of organic matter and soil. If your soil is very heavy, it may pay to buy extra "black dirt" for this purpose. While ordinarily I advise against buying outside soil because it almost always is full of weed seed, composting destroys these seeds so they do not become a nuisance.

Between each layer, sprinkle a little chemical fertilizer. Except for fish emulsion, dried blood and urine, organic fertilizers are not desirable: they, too, must be rotted down before they become useful as fertilizers; thus they add little to the action of the pile at first. The layers can be added one at a time or the entire pile built at once—whichever the available supply of organic matter dictates. As each layer is placed, it should be wet down enough to moisten it thoroughly but not so much that it is soggy.

TIME TO TURN

Whether all the layers are laid down at the same time or over a period of several weeks, the entire pile should be turned over and mixed one month after it is completed. The chief benefit of this is to release any excess carbon dioxide that may have accumulated in preliminary decomposition, as well as to give bacteria additional oxygen. The pile may have to be wetted down if it looks dry after turning. Turn it over again three or four weeks later. If the pile doesn't seem to be rotting down rapidly, add more fertilizer at this time.

Under ideal conditions—outdoor temperatures in the 70s or above—the compost should be ready to use in about three months. In estimating when a particular lot will be done, don't count any month when air temperatures average below 50 degrees. Under such cool conditions the inside of the pile stays warm but the decomposition of the outer layers slows up.

Absolutely *any* organic substance can be composted (the previous chapter discussed fatty, greasy and oily materials). Dead animals, bones, table wastes, lawn clippings, leaves, weeds, plants pulled from flower and vegetable gardens, hair, wood shaving and sawdust, spoiled grain, clippings from wool goods and many other organic substances are all good raw material for composting.

A GOOD START

Special starters or "compost activators," along with weird mixtures of herbs and other sophistications, are often recommended to "improve" the quality of the finished compost product. These mixtures include bacterial cultures containing strains that continue working at lower than normal temperatures. They have some value in speeding up decomposition during cool spring or fall weather. Just as effective, however, if available, are bacteria-filled screenings from an old compost pile, well-rotted manure or soil from a rich field. If the only soil available for building a compost pile is a sandy loam, a commercial compost culture will speed breakdown. These should be cultures of bacteria such as Activo, not the herbal mixtures frequently mentioned in organic gardening publications.

There is no reason why the pile should have an offensive smell if properly covered with soil: a 4-inch layer of earth absorbs all odors. However, if blood, manures and other rich organic substances become a bit odoriferous, add a little extra superphosphate. One caution should be given: do not add large amounts of *fresh* wood ashes to a compost pile as they form lye and can injure bacteria. Mix fresh ashes with a little damp soil and allow them to stand for a day or two, after which they can be used safely.

ORGANIC MATERIALS WHICH CAN BE COMPOSTED

Dried Leaves: This is the most common material available to home gardeners. It is valuable as a source of humus, but don't take seriously the "richness" of this material often mentioned by uninformed individuals. Before trees and shrubs drop their leaves in autumn, they withdraw starches, sugars and other food elements from the leaves. Leaves are largely cellulose, so additional starches as well as nitrogen are needed to rot them. Leaves are best if mixed in the compost heap with such materials as stale bread, spoiled flour or meal, and so on.

Table Wastes: Richness of this source depends on how extravagant you are. The higher the percentage of meat scraps in table waste, the more valuable it is in compost.

Sawdust: If the master of the house has a home workshop, or if sawdust and shavings are available from a local source, wood wastes make excellent compost. If wanted as a source of humus, use plenty of nitrogen with these wastes, but if you want compost that is less completely converted to humus, add more starchy material and less nitrogen to the pile.

Chicken Manure and Poultry Wastes: Local broiler plants often throw away offal, feathers, etc. Many poultry raisers find chicken manure a nuisance and are glad to give it away; it is sufficiently high in nitrogen but not in phosphorus and potash. These two elements plus starch should be added to speed up chicken waste breakdown.

Brewery Wastes: The spent hops from breweries are about on a par with leaves and require about the same composting attention. One difference: hops are usually wet when received.

Seaweed and Kelp: If you live near the sea, don't scorn the sea's free gift of kelp and seaweed. These are high in potash as well as many minor elements. Additional nitrogen helps speed breakdown.

Nut Shells: Pecan shells, peanut husks, cocoanut fiber and other nut wastes make excellent compost. One precaution: avoid shells of walnuts. They contain a chemical that inhibits plant growth and works like an antiseptic to kill off bacteria.

Tobacco Stems and Wastes: An excellent source of humus and a good soil conditioner when composted.

Fish Wastes: When cleaning fish, always save the offal for the compost pile. Salt-water fish in particular contribute all the minor elements as well as the three major elements in their skin, bones and offal.

Wool Clippings: Worn-out wool clothing should be buried in the compost pile. It will take about two years to decompose. Dark colors rot more slowly than light tones.

Corn Cobs: Although rather high in silica, corn cobs do contain considerable potash and thus are useful in the compost heap. Both nitrogen and phosphorus (at least a sprinkling of the latter) will improve the compost produced by corn cobs.

Sewerage Sludge: If it can be had for the hauling, air-dried sewerage sludge is worth composting. However, be sure it goes through at least a full year's decay before it is used. Amoeba can survive in sewerage sludge and cause infection in human beings. A full year's composting, if the pile is turned, should eliminate them.

Lawn Clippings: They should be added to the compost heap rather than allowed to lie on the surface of the lawn, where they build up a duff that fosters fungus diseases. Allow the fungi in the compost pile to work on them instead.

Straw, Hay, Cattails: These are low in nitrogen. A compost "food" is needed to rot them. The finished product closely resembles barnyard manure.

Weeds and Discarded Plants from the Garden: Use these only if not visibly infected with plant diseases. If weeds have formed seed, be sure to place them deep in the pile so the heat of composting will kill the seed.

Tanbark: Not easy to find nowadays, but if available it can be composted with the "food" mixture recommended for straw.

Cotton Nolls and Wastes: Difficult to start a compost with this type of material, but it yields a high percentage of humus. Allow about a year for breakdown.

Paper Scraps: Mentioned here only because paper is often a subject of doubt. Almost pure cellulose, it requires both nitrogen and starches or sugar in order to break down. A small percentage of paper in the compost pile won't hurt. Actually, practically anything of organic origin can be composted in time. I once made some excellent compost with a mixture of straw and some spoiled latex paint, combined with waste blood-albumin gluel

APPLYING ORGANIC MATTER DIRECTLY TO SOIL

Where space or time does not permit you to operate a compost heap, organic matter can be applied directly to the soil. If this is done in late fall or early spring the organic material should be sprinkled with fertilizer and plowed under. During the growing season this method is impractical. If not offensive in odor, organic matter can be used as a mulch over the soil and worked into the ground after the growing season is over. Here it is important to remember that even though only the lower surface of an organic mulching material is in contact with the soil, rain and sprinkling will wash starches and sugars down from it to the soil organisms which consume nitrogen. Gardeners often are surprised to find their plants turning yellow following the application of a mulch. This can be avoided by the use of a good mixed fertilizer on the soil before the mulching material is applied.

The question is often asked, "How *much* fertilizer should I apply to compost or to soil on top of compost?" There is no exact formula for this, although a rough rule of thumb is four ounces of actual nitrogen to each bushel of organic matter. This is a much heavier dose than would be applied to garden soil, but it must be remembered that there are well over a million bacteria in a teaspoonful of soil and they can use far more plant food than seems possible. Remember, in the compost pile you are working for maximum efficiency of these soil organisms without depriving plants of nitrogen.

SHEET COMPOSTING

Sometimes a piece of land lies idle for some time, as when property is purchased in anticipation of building a home at a later date. Under these conditions, soil can be built up by what is known as sheet composting, or green manuring. Various plants, such as winter rye (the cereal grain, not rye grass), vetch and buckwheat, are commonly used for this purpose. In the South, lespedeza and kudzu vine are also used.

The green manure cover crop is sown whenever convenient, even in midsummer if artificial irrigation is available. Seed should be sown quite thickly, since the idea is to produce a dense cover to keep down weeds, as well as to grow organic matter to be plowed under. The use of fertilizer in liberal amounts (to a maximum of eight pounds of actual nitrogen to 1,000 square feet) is recommended. This nitrogen will not be wasted, since most of it will be built into plant tissues as protein, which will again be available to lawn grasses or garden plants when the green manure is plowed under and rotted down.

If this process is repeated for a year or two, an amazing amount of organic matter, which finally breaks down into humus, will be added to the soil. Winter rye is particularly useful for this purpose because if sown in fall it will continue to grow every time the soil thaws in winter. After winter rye is plowed under in spring, a crop of buckwheat or vetch can be seeded, giving a double supply of green matter for sheet composting.

Do not, however, try to squeeze out too much growth the year the property is to be put into lawn or garden areas. If these areas are to be planted in spring, the winter crop of rye should be plowed under at the earliest possible date in late winter or early spring to allow for initial decomposition before seed is sown. If the lawn is to be seeded in August, plowing should be done some time in July. Be sure to apply fertilizer to the cover crop before turning it under, whether this is done in spring or in fall.

THANKS TO SYNTHETICS

The roles of lime, marl and ground limestone in flocculating clay and silt have already been mentioned. Synthetic chemical soil conditioners, introduced with such a fanfare of publicity in 1952, are disappearing from the market. But they should be mentioned because of the contribution they made in calling attention to the need for soil amendment. To no small extent, awareness of this subject may be said to stem from this publicity.

Partly because of their high cost, the products introduced are not likely to come back in their present form. But with the idea once started, who knows what combination of science and commercial enterprise may find a way to make new forms of such materials practical and economical?

PHYSICAL CONDITIONERS

Another method of improving soils is to add minerals which increase porosity by mechanically opening soils to air and water. One of the oldest materials used for this purpose, a favorite with British gardeners, is ordinary sand. The addition of enough sand to a stiff clay soil should, in theory, separate the particles so that air and moisture can move in freely and thus "correct" the soil so it will crumble readily when squeezed into a ball. Sand should also provide pore spaces in which bacteria and fungi can thrive. This in turn would gradually improve the humus content so that a clay soil would turn into a clay loam. Unfortunately, this end is not always reached when sand is added to clay. Large amounts are needed to bring about any worthwhile improvement. In the final mixture of the two there should be at least one third sand and not more than two thirds clay. If sand is used too sparingly it will, instead of separating the clay particles, merely act like the aggregate in a concrete mixture. The individual grains will be cemented together by the much finer clay particles to form an almost impervious solid. I once saw a stiff clay to which 20 per cent sand had been added; the mixture was so hard it resembled a cement sidewalk. But when another inch layer of sand was spread on top of the soil and worked in with a rotary tiller, the whole mass crumbled and fell apart as if by magic.

For this reason, if sand is to be used to modify clay, say to a depth of 6 inches, at least a 3-inch layer of sand should be spread over the entire area.

This makes sand a somewhat expensive soil conditioner if a sizable area is to be treated.

OTHER MECHANICAL CONDITIONERS

One of my favorite low-cost soil amendments is steam cinders. These sharp black particles are the product of burning coal in steam power plants. Because of high temperatures reached in the firebox, individual particles are partially vitrified. They are quite porous, which allows them to absorb a lot of moisture.

They can often be had for hauling. Municipal and private power plants accumulate them much more rapidly than they can be used for construction work, roads, and so forth. I pay about a dollar a yard, which makes steam cinders about the cheapest soil amendment I can buy of any kind.

They are particularly useful in improving lawn soils. They might not be so desirable in a vegetable garden where their harsh, gritty particles would be a nuisance to the gardener working around root crops. I have, however, used fine steam cinders in bulb and perennial beds.

The cinders have two drawbacks. One is that they must be purchased many months before they are needed. When fresh, they contain sulfur impurities which must be leached out before the cinders can be used. I buy them in late summer, pile them behind the garage over winter and use them the following spring. Weathering does a much better job of purifying them than can be done with a hose and water under pressure.

The other defect is that hard, rough clinkers of considerable size are often formed by some coals. This means that the pile must be screened to separate the unusable particles from the fine ones.

POROUS MINERALS

Two "expanded" minerals—vermiculite and Perlite—have one thing in common—a porous structure which enables them to absorb enormous amounts of water. They are excellent soil conditioners and, unlike either organic matter or chemical conditioners, they remain practically unchanged for years. They are chemically inert and not readily attacked by soil acids or alkaline solutions. While more expensive than most other materials, they have very definite advantages. Clean, easy to handle, readily available and, for all practical purposes, sterile when they come out of the bag, they are convenient to use for seed starting or cutting propagation, for house plotting soils and for small garden areas.

If the material is to be visible at the soil surface I prefer vermiculite because it looks more like soil. The white color of Perlite produces a soil mixture that is less natural in appearance. Where the soil is to be used for lawn purposes this surface color factor is unimportant since the Perlite will be hidden by the grass.

Both Perlite and vermiculite can be used in amounts up to one third the total volume of the soil. However, they need not be used as freely as sand. Relatively smaller amounts of either material will bring about noticeable improvement in a sou*.

CHAPTER DIGEST

A compost pile (two would be better) is the mark of a knowledgeable gardener, for it is an invaluable source of the vital humus that builds Gardener's Loam. Anything organic can be added to a compost heap, and only a very few rules govern its operation. Many common and some uncommon compostable materials are discussed, along with the use of certain "compost starters."

The best soil conditioners are "natural" materials (organic and mineral), whether used on top of or in the ground. They are far superior—in their action and durability—to the overrated synthetic chemical conditioners.

Chapter 9 Microorganisms Live and Die For You

SOMEONE has said, and not too inaccurately, that soil management is nothing more nor less than the care and feeding of bacteria. Kill them off and what is left is no longer a true soil but an inert mass of rock debris contaminated with remains of dead plants and animals—wastes that without organic breakdown must remain permanently fixed in their sterile grave. Although they have an almost split-second life span, microorganisms such as bacteria, fungi (including mycorrhizae), actinomyces, rotifers, and protozoa are all vital to the reduction of organic and mineral wastes into plant nutrients, thus recycling the elements of existence from one generation to the next.

Fortunately for mankind as well as for all living things, these organisms are doggedly invasive and wonderfully capable of finding their way to places where they are needed. Few spots on earth are unfit for them to do their vital work. (By microorganisms is meant all living organisms, whether of plant or animal origin, that are too small to be seen with the naked eye.)

When we speak of the microorganisms of the soil, we are speaking of a living, throbbing community of well-nigh infinite numbers. Is it any wonder, then, that air, moisture, food and growing conditions are so vital to the production of Gardener's Loam? These trillions upon trillions of cells need to be fed, watered, warmed and protected so they can carry on their many functions in safety. Perhaps the most important single service performed by soil organisms (particularly bacteria) is to supply nitrogen in a form that can be used by higher plants and eventually by man. *They do so in two ways: {1) by direct fixing of nitrogen from the air, and {2) by releasing nitrogen locked up in organic matter.*

DIRECT NITROGEN FIXATION

There is no general agreement among microbiologists as to the extent of direct fixation of nitrogen by soil bacteria. Most authorities agree that *Azotobacters* (there are several species) carry on a process known as non-symbiotic fixation (to distinguish it from nitrogen fixed by bacteria on the roots of clovers and other legumes). Non-symbiotic fixation is aerobic; that is, *Azotobacters* work only in the presence of oxygen. Another direct-fixation type, *Clostridium pastorianum,* is what is known as a facultative anaerobe; that is, it can work either in the presence or absence of oxygen. This last form is thought to take its nitrogen from ammonia in soil gases, thus preventing the ammonia from escaping into the air.

These direct-fixation bacteria work best when they have access to plenty of calcium, carbon dioxide and glucose. At a pH of 5.5 or below, nitrogen fixation practically comes to a standstill. Potassium chloride (muriate of potash) is particularly harmful and stops all action.

The amount of nitrogen these direct-fixing forms are capable of capturing is not definitely known. At Cornell, a series of accumulation tests gave figures of approximately 40 pounds per acre per year. Other authorities have given figures as high as 1,000 pounds per year per acre, but these seem unrealistic.

We might say that direct fixation is important, certainly, to native soils, woodlands, pastures and unplowed fields. It cannot possibly satisfy the needs of flowers and vegetables in home gardens, or the needs of crops like corn and grains which can blot up a couple of hundred pounds of nitrogen per acre per year.

Attempts have been made to isolate and improve superior strains of both *Azotobacters* and *Clostridium* so that pure cultures could be added to composts and soils. So far these efforts have been disappointing. Part of the difficulty lies in supplying the cultures with calcium, carbon dioxide and glucose without building up competing populations of more aggressive soil organisms. The use of potassium phosphate, suggested as a source of potash to help preserve nitrogen-fixing bacteria, has not resulted in significant improvement.

NITROGEN RELEASE BY NODULE BACTERIA

Baptisias, lupines, sweet peas, clovers, alfalfas, lespedezas and other legumes—plants belonging to the *Leguminosae* or pea family—produce nodules or tubercles on their roots when attacked by certain bacteria. These bacteria are able to fix free nitrogen from the air, or at least capture ammonia gas that might otherwise escape into the atmosphere. Originally called *Rhizobium radicicola,* nowadays these are usually classed according to the plant they inoculate, such as *R. trifoli* for the bacteria that live on clover roots. For simplicity's sake, let's call them nodule bacteria.

The various nodule bacteria are quite specific and will not inoculate all leguminous plants. One that inoculates garden beans will not invade the roots of peas. Lupines have a specific strain peculiar to them alone, and so on. To get around this the Nitragen Company, which probably sells 95 per cent of all the garden inoculants used in the United States, has developed a mixture of all the strains needed by various legume plants.

Some members of the *Leguminosae* do not harbor nodule bacteria (the redbud or Judas tree, *Cercis canadensis,* is one), but all lupines, baptisias and other herbaceous species within the family do.

As green manure or sheet composting crops, vetch, clover and others are just as valuable for their nitrogen contribution today as they were centuries ago when farmers grew them and plowed them under without knowing why.

DOES INOCULATION PAY?

In soils already rich in nitrogen, little or no N-fixation occurs, even if seeds or plants are treated to be sure inoculating bacteria are present. Nevertheless, inoculation is worth while, since there is a chance it might add a little nitrogen to the soil. The cost of inoculation is so low that it is not worth considering. Results can be checked by direct observation of plants: if roots are covered with hard knots when pulled up in fall (barring a serious infestation of nematodes), chances are good that a gain in nitrogen was effected.

One other group of plants, the alders, can work like the legumes. A different organism is responsible, but it, too, fixes atmospheric nitrogen.

MYCORRHIZAE

The fungi called mycorrhizae are discussed at this point rather than later in the chapter with other fungi because they once were thought to be capable of fixing nitrogen from the air. This theory is not considered valid at this time, but so little is actually known about these fungi that scientists will not make definite statements as to their function. Mycorrhizae cover roots of certain plants like azaleas, rhododendrons, blueberries and beeches with a felt-like sheath of mycelium. Once this sheath covers the root system of a plant, few or no root hairs are produced—the sheath of mycelium seems to function in their place. Apparently the fungus is able to predigest food from soil, to take ammonium compounds from the soil and feed them to the host plant. The fungus cannot, as far as I can learn, use ammonia gas directly.

Since most of the plants to which mycorrhizae seem to be important grow in acid soils (where full breakdown of ammonium compounds into nitrates is slow or non-existent), the fungus probably enables its host to survive where otherwise it might starve for lack of nitrogen.

Significantly, cultural practices which protect and stimulate mycorrhizae are best for the host plant as well. These include increasing organic content of soils, supplying constant moisture without saturation, aeration of the soil, and mulching to protect the soil from too much heat and from drying.

NITRIFICATION

The conversion of complex proteins to usable nitrate compounds can be called nitrification (years ago it was called ammonification). The critical step in the nitrification process, in so far as the conservation of soil fertility goes, is in the *release of ammonium products.* If the wrong kind of fermentation of the proteins takes place at this point, or if the right bacteria are not present to take up the gas, free ammonia may be developed and escape to the atmosphere. A good example of this is in a pile of fresh manure, where certain bacteria secrete an enzyme called urease, which transforms urea into ammonium carbonate. This is an unstable compound, and readily lets go of its contained ammonia, which produces the characteristic sharp smell of manure.

What science is working to develop (and what gardeners would introduce into the soil artificially if they were available) are large colonies of *Nitrosomonas* and *Nitrococcus* bacteria, which convert the ammonium products into nitrites. To carry on the process, these bacteria would then be supplemented by even larger numbers of *Nitrobacter*—the forms that convert nitrites into nitrates.

Temperature affects the nitrification process. Most of the bacteria involved do their most effective work in soil temperatures from about 70 to 85 degrees F. At temperatures below 50, they are quite inactive. Excessively dry or wet soil conditions also interfere with their effectiveness.

As always, these bacteria require energy foods to keep them alive—the starches and sugars that they can get only from decaying organic matter.

DENITRIFICATION

Unfortunately, the nitrification process is reversable, so if conditions are not right we have denitrification—nitrates produced as the end product of this long chain of organic breakdown revert to nitrites and ammonia. Several microorganisms exist which will do this. They are favored by anaerobic conditions (lack of oxygen) and by presence of liberal amounts of fresh, decomposing organic matter. This is one reason for maintaining two or more compost piles instead of continually adding fresh material to one old pile.

FUNGI

The role of fungi in the soil has not been as thoroughly studied as has the role of bacteria. Fungi, however, must also find their energy foods in organic matter. In breaking down organic material, fungi often do a better job of dissolving cellulose than do bacteria. They can often work where bacteria cannot. For example, fungi often invade a duff or mull on the surface of soil and begin working on the material before it can sift down far enough for bacteria to attack. Fungi need less soil moisture to survive and so continue to work after drought has checked bacterial decay action.

Fungi survive and remain active at pH readings much lower than those tolerated by bacteria. No fungus, however, with the possible exception of mycorrhizae, can fix nitrogen.

The exact role of antibiotics in soil is uncertain. Whether these substances (which are produced by a number of different fungi) are helpful or harmful to higher plants has not been fully explored, although at least one such product is used to control fire blight in pears and apples. We do know that these antibiotic substances are plant antagonists, not affecting the fungus that produces them but inhibiting or poisoning other fungi and bacteria.

CHAPTER DIGEST

The old saying "Dynamite comes in small packages" could have been coined for soil microorganisms. They are microscopic, but in their living and dying process they play an indispensable role: Without them the soil is "dead"; with them the soil is alive itself and is capable of giving life to plants. Although bacteria, fungi and all the others perform innumerable soil services, the crucial one is conversion of nitrogen into usable form for plants.

Bacteria that live on the roots of clovers and other legumes, for example, add significantly to a soil's supply of nitrogen. Fungi serve a different but highly important function in breaking down the soil's organic and mineral materials into plant nutrients.

Chapter 10

The Misunderstood Earthworm

CONTRIBUTIONS of various kinds are made to garden soils by "organisms" other than fungi and bacteria. I refer to creatures that live at least part of their lives in soil and are large enough to be seen with the naked eye. Most of them are outright garden or lawn enemies and are discussed (with recommended control measures) in Chapter Fifteen. The earthworm, however, defies such simple classification. Is it a "good guy" or a "bad guy"? I shall try to bring an answer—or at least a better understanding—out of the fog of controversies, misinformation and half-truths that surround the earthworm today as they have for many years.

Especially during the past two decades, flamboyant and extravagant advertising has created a picture which is completely false and misleading. The earthworm has been credited with being the source of all true fertility (ignoring completely the much more vital role of other soil organisms). It has been hailed as the savior of mankind. Articles have actually appeared in print which blame increases in human cancer on the destruction of earthworms by chemicals and modern tillage methods 1

DARWIN DATA

The authority most frequently quoted to back up these claims is Charles Darwin, who in 1885 wrote a book, *The Formation of Vegetable Mold,* in which he reported his observations of the role of earthworms in soil formation and modification. This was a sound piece of observation, and obviously the work of a man familiar with the scientific approach to problems. Although today we can add a few facts to his original observations, we cannot refute his conclusions. The difficulty lies not in what he said about earthworms but in how his account has been "doctored" or misinterpreted.

Darwin reported (and his findings have been confirmed by later observers) that earthworms in an acre of ground move as much as 15 tons of soil a year. This adds up to a layer about 1/lOth of an inch deep over the acre. This does not mean they move only the upper 1/lOth inch, since they do go quite deep at times. However, the total mass moved from place to place in a year's time will equal that amount of soil. And this gives the worm credit for always turning over fresh soil, when it is obvious that considerable backtracking is inevitable so that the same soil may be moved several times a year. In any case, earthworms would take 70 to 100 years to turn over the same amount of soil that a man can turn over in one hour with a rotary tiller. Thus the soil-turning efforts of earthworms seem rather far from the magic process described for us in such glowing terms by earthworm-farm advertisers.

RIGHT SPECIES

The proper species must be present in the garden and, of course, in the cultures introduced from commercial sources. There are a number of earthworm species that occur in European and American gardens, but only two are important. One of these is *Lumbricus terrestris,* a dark red species found in soils that have a high organic content; the other is *AUolobophora calignosa,* a grayish-pink species which does not require quite as much organic matter to survive.

In both species, the body is made up of interlocking segments, interrupted about one third the way down by a smooth area known as the girdle.

Since these two species are the ones which propagate most readily in ordinary garden soils, one might reasonably expect to find one or the other in cultures supplied by commercial earthworm farmers. This is not the case. I have never found either species in the cans or packages supplied by earthworm farms.

The worm cultures used for worm propagating at such farms are usually mixed with large amounts of protein compounds and organic matter. As protein breaks down, it passes through a stage where ammonia is released. Ammonia is harmful to most earthworms and may even kill the two species already mentioned. For this reason, the earthworm farmer propagates only the manure worm, *Eisenia foetida,* which is capable of surviving and propagating in the presence of ammonia. Unfortunately, this one *is incapable of surviving in clay or loam soils unless these have been freshly manured.* As a result, about the only place they will survive in the average garden is in the compost heap. Directions accompanying shipments of worms usually recommend placing them there.

All earthworms (with the exception of tropical species outside the scope of this book) must have soils that are high in both organic matter and moisture, but the manure worm has the highest requirements of all in this respect.

As for the hybrid worms offered by advertisers in organic gardening publications, these may exist but I have not seen any hybrids which were recognized by taxonomists familiar with these creatures. Species of earthworms tend to remain in special habitats so that opportunities for crossing are limited between species within the same genus.

Most earthworms are hermaphrodites, so that, in mating, both individuals fertilize each other. Since they live in habitats of a single species as a rule, this cuts chances for hybridity in half, even if it were possible. In other species, parthenogenesis eliminates crossing altogether.

CREATING VS. CONSUMING

A great deal of fuss is made of the role of earthworms in "building rich soil" through their castings. As is well known to scientists, but apparently not to organocultists, *earthworms are incapable of surviving unless the soil is rich.* Unless fertility, texture, structure and organic content of a soil are to the liking of worms, they will not live and breed there, or remain there if they are introduced artificially. This may come as a shock to those who have spent good money for worms in an effort to build up poor soils.

Equally true is that earthworms are far from being the powerful allies promised in extravagant advertising. Earthworms have no mechanism for creating plant foods, for capturing solar energy or for fixing nitrogen from the atmosphere.

To some small degree, earthworms may make available some deeply-buried fertility that would not be available to shallow-rooted plants like petunias and alyssum. *Most plants,* however, even lawn grasses, *are capable of sending their roots as deep into the soils as earthworms normally burrow.*

In the process of living, the earthworm uses up or degrades energy instead of creating it. For this reason, *the worm makes the soil poorer rather than richer by the amount of energy it has burned up and passed off as carbon dioxide.* Even when the worm dies and its body returns to the soil to increase organic content, that contribution is reduced by the amount of energy the worm used during its life.

Worms redistribute richness rather than create new food elements. In relatively poor soils, but rich enough to keep earthworms alive, the grass may seem greener in spots where castings are heaviest. This comes from the very small amount of nitrogen excreted in the castings. Similar effects can be observed when earthworm "manure" is used on poor soils.

THE PRICE YOU PAY

The "richness" of earthworm castings is a myth so ridiculous that it is difficult to understand how it ever got started. It is clear that before making such claims, the sellers never took the trouble to chemically analyze the castings for nitrogen. I have done so: I purchased a $1 package weighing eight ounces and had it checked by an independent testing laboratory. The nitrogen content was determined as 5/l,OO0ths of an ounce of actual nitrogen. At that rate, nitrogen would cost *$200 an ounce.* With nitrogen at about 70f* a pound from commercial sources, this seems like a terrible price to pay just to keep a myth alive.

One Western state insists that even natural manures must carry fertilizer analysis tags (these are usually only required on mixtures of chemical fertilizers). One "manufacturer" of a worm-castings product tried to show the nitrogen reading in parts-per-million to make it sound more impressive. He was, however, compelled to mark his package as containing .005 per cent nitrogen, less than the nitrogen content of some drainage waters.

FEEDING HABITS

This low percentage of nitrogen in worm castings is not surprising when the feeding habits of the two common worm species are studied. They eat by dragging long strips of leaves or grass down into their burrows. In forests, their diet consists of fallen leaves, even during the summer months. Instead of seeking out other plants on which to feed, they prefer to work on and grind down the leaf fall of the previous autumn.

They are amazingly selective in their food, with a strong preference for leaves of certain kinds of plants. In brushing over the leaf cover in a mixed grove of maples and oaks, I was surprised to find that the only remaining leaves in spring were from oaks, while maple leaves had been consumed except for the tough leaf stems. In another grove, where oak, ash, dogwood and hickory were growing, leaves of oaks again were left behind. Leaves from hickories were eaten first; only then were the others touched.

In another forest, basswood, sugar maples, red maples, aspen and white pines were growing together in a mixed planting. The pine needles were untouched for two years, while basswood and aspen leaves were eaten completely. Maple leaves were attacked only after basswood and aspen leaves were stripped down to the last petiole. Herein lies a possible explanation for the slow breakdown of oak leaves in forest litter, as well as for the durability of pine needles when used as a mulch. Also, in both cases, bacteria and fungi have a hard time breaking through the outer cells of the foliage, so decay is delayed.

The important fact here, however, is that the preferred leafy diet of earthworms is relatively low in nutrients. If you analyze the mineral content of fallen leaves you will immediately realize that they are indeed very poor fare (as explained in the reference to leaves for composting in Chapter Eight). In order to stay alive, an earthworm must exist at a slow pace, yet consume enormous amounts of low-nutrient foods. It is interesting to note that when worms live in lawns, they feed only on grasses, never on nitrogen-rich clovers.

THE AERATION NOTION

Another claim made for earthworms is that they "aerate" the soil. Compared with the aeration effected by a single plowing, this is insignificant. Even in a lawn, earthworm aeration is more imagined than real. Worm burrows are of small diameter and quite short in length (at least in summer) and practically always plugged with a wad of grass. Since the burrows are open only at one end and are lined with a thin coating of lime, the amount of air that can move in and out is infinitesimal. This "aeration" is not the same as the movement of gaseous vapors between particles of a well-aerated soil, where gas dispersion takes place in all directions.

The slight aeration that earthworms do provide is more than offset by the harm done in spreading infection. Here we are not concerned with the role of the earthworm as a carrier of diseases to animals, but with its part in spreading organisms of plant maladies. I have seen a valuable planting of delphinium, for example, destroyed by mustard seed fungus when earthworms pulled infected plant material into their burrows between the plants. In an adjoining planting of delphiniums the soil had been treated with arsenate of lead for Japanese beetle control (which, of course, destroyed earthworms in the process). Here not a plant was infected.

Earthworms rely on lime for proper functioning of their digestive apparatus, and this limits them to soils that are neutral or alkaline. They are never found in strongly acid soils.

A LAWN EVIL

Another mark against the earthworm is its destruction of smooth lawn surfaces. Its ability to ruin putting greens is well known. The day-by-day deposit of castings is bad enough but can usually be partially overcome by regular mowing. The real trouble occurs in winter, particularly if snow falls early and remains on the surface most of the winter. Protected under a blanket of snow, soil remains unfrozen and worms are able to work night and day without interruption. The height of their mounds under snow may reach one to two inches but it is difficult to judge because, as snow melts, the mounds usually are broken and spread over an area of several inches.

Earth thus brought to the surface leaves the lawn so uneven that the owner is compelled to roll it and thereby compact the soil, which more than offsets any slight improvement in aeration effected by the worms. Where owners complain of rough, uneven lawns and "heaving" of grasses, I often recommend treatment with chlordane, calcium arsenate or dieldrin to rid the soil of earthworms (and grubs) so that the need for rolling will not recur.

CHAPTER DIGEST

Do earthworms have any value in soils? Yes and No. In gardens, but not in lawns, we might make out a case for them as processors of organic matter as well as redistributors of plant foods. This may be partial repayment for the energy and nutrients they use up in the course of their life. Another demerit is the harm they do in spreading plant diseases and in depositing unsightly casts on lawn surfaces. Perhaps it all boils down to this: Except in special cases, earthworms do not do enough harm to warrant the cost and labor of destroying them, or enough good to justify special efforts and expenditures to increase their numbers. A good soil will naturally and automatically have an adequate supply of earthworms; a poor soil will not attract them or support them if they are introduced.

Chapter 11

Water and Air—A Vital Pair

PLANT life is intimately bound to water. Air is equally vital in the soil as well as, of course, above ground. In fact, these two are partners; they operate harmoniously in the soil to the advantage of plants growing therein. But water—or rather, the lack of it—is generally more troublesome.

No part of the United States, whether fog-shrouded islands off the coast of Maine, a Midwestern prairie or a seashore spot in California, has escaped periods of drought during which not enough rain fell to maintain plant life. Most sections of the country can expect droughts like this about one year in four.

More often than not, water needs of plants are not considered until cultivation, fertilization and other contributions to growth have been provided. Watering is frequently given no thought until heavy rains of spring and early summer have evaporated and growth begins to show signs of suffering for water. However, if full advantage is to be taken of time, effort and money expended to build up Gardener's Loam, provision for a *reliable water supply should receive attention in the initial garden planning.*

A BASIC FOOD

Above all, water is a food. Less than 2 per cent of plant tissues are composed of minerals absorbed from soil elements; roughly 98 per cent of the tissues come from air and water. Even the 2 per cent from soil can enter and move through plants only in soluble form. It has been estimated that to produce a single pound of dry matter requires absorption, use and evaporation of at least 700 pounds of water. Of this, less than 1 per cent is retained in plant tissues, either as moisture or as elaborated food. During a single day, a mature tomato plant gives off as much as a gallon of water, while an acre of hay during a single growing season may transpire as much as 700 *tons* of water.

All this water is derived from soil except for the little absorbed through foliage from dew and rains. Consider where this soil water must come from. In humid parts of the country, it accumulates from snows in winter and heavy rains in spring, with a somewhat smaller accumulation from summer and fall rains. During dry periods, some gardeners may have to add as much as 10 per cent of a season's water supply from city mains or wells. Many gardeners never water at all. In dry districts as much as 100 per cent of the total water needs of plants must be supplied by irrigation. This does not mean that in humid climates artificial watering should be neglected. Often the application of a little extra moisture avoids stunting or slowing of plant growth by preventing plant tissues from hardening. The added moisture may be small in volume but, because it comes at a critical time during the growing season, often makes the difference between a good garden and one that is at best mediocre.

A private well is a fortunate solution to watering problems. The well need not be elaborate. A driven pipe with a pitcher pump can supply all water needed for emergency irrigation in most areas. Electrical or gasoline-driven pumps are not expensive and will ease the pumping chore.

DOMESTIC WATER SUPPLIES

Sometimes untreated ground water is too loaded with undesirable salts to be usable. Here the gardener must depend upon local municipal sources for water other than that supplied by rain. The first thing I did when I bought my present home was to order 200 feet of %-inch copper pipe, which is cheap, durable, easy to lay and will withstand some freezing even if not properly drained. Placement of water taps at convenient intervals allows me to quickly sprinkle the entire back yard if necessary. I am fortunate in having a 1 ^4-inch copper pipe to the street, which gives me plenty of pressure. If you are building or repairing your house, I recommend that you have that size of pipe installed.

AN EARLY START

Except for my Merion Kentucky bluegrass lawn, which does better if it is run slightly dry, I don't wait until soil dries out before I start irrigating. Rather than allow the accumulated moisture of spring to pass off, I *start applying water as soon as we go for a week without rain.* I then turn on the sprinklers and keep them running until the soil is moist six inches down. Of course, that does *not* mean I have put on an over-all six inches of water: in a true Gardener's Loam the organic matter provides many pore spaces throughout the soil mass that trap air in little bubbles. Many of these pores are so small that water bridges over them by surface tension and does not enter.

I find that when I apply 2% inches of water, *as measured in coffee cans set at intervals,* moisture will have penetrated approximately six inches. Every gardener should check the water intake capacity of his soil by actually measuring how much water penetrates to what depth. With experience you can learn to judge moisture by feel. Once you have felt your soil when it is in good tilth and adequately supplied with moisture, you will be able to judge the condition of the soil by merely picking up a handful and giving it a squeeze or two.

ORGANIC SOIL SPONGE

Soils high in humus and other organic matter always dry out more slowly than do sandy types that allow water to run through with little or no absorption. An interesting fact is that when soil does a good job of blotting up moisture, this also takes care of the problem of air supply. As already pointed out, true Gardener's Loam can carry large amounts of moisture without losing its capacity for holding air. Soils in gardens vary between 35 and 65 per cent pore space. Water is held in these spaces in three forms—as free water (usually in vapor form except when soil is "drowned" out with excess water), as a film on the surface of soil particles, and as absorbed water inside porous minerals and organic particles. Air and water, while partners, are antagonists too. They move together into pore spaces when conditions are favorable for growth, but at times excess water can drive out air.

We should not think of the air in pore spaces as identical to the air of the atmosphere. For one thing, soil air contains about six or seven times as much carbon dioxide (in soils containing any amount of organic matter) and is slightly poorer in oxygen. This is due to constant absorption of oxygen by roots, leaving carbon dioxide behind. Leaves, as we know, absorb carbon dioxide from the atmosphere and use it to manufacture carbohydrates. If pore spaces are so small that soil "ventilation" is poor, the result is a build-up of carbon dioxide because more oxygen cannot move in to replace that removed by roots.

Small pore passages are the mark of clay soils and other fine-textured types. This makes clay soils difficult to aerate and drain. Large pore spaces are non-capillary; that is, they are normally filled with air because they are so large in cross section that gravity can pull excess water out of them. This is what happens in soils high in sands. The ideal soil condition is one where sand, clay, silt and organic matter provide a soil with large crumb particles. These allow moisture to drain off readily, but inside the crumbs are small air-holding pore spaces which cannot be drowned out. The organic matter serves as a soil sponge to absorb reserve water.

PLANTS CAN DROWN

Some plants, notably cattails, sedges and others that live in bogs, can survive with their roots in water. Others can tolerate a soil where pore spaces are close to saturation but contain some air. Most garden plants, however, do best when practically all the water in pore spaces is in vapor form, when film water is close to capacity, and when absorbed water is high. This is the invaluable "moist, well-drained soil" about which many garden experts write so much and so vaguely.

If our ideal Gardener's Loam has been built up, the only barrier to correct control of air and water is drainage. This is a basic requirement, but it is often left to chance. I have seen carefully-worked gardens where a loose, friable soil had been created, but no provision made to lead away water which found this loose soil easy to penetrate. As a result, the area (surrounded by an underlayer of hard clay) became a "bathtub" into which moisture drained, forming a swamp during wet weather.

To check drainage, try to obtain a water-tight barrel or a steel drum that holds about 50 gallons of water. Fill this and then upset it over your garden plot or lawn. If the water soaks in within a few minutes without forming puddles, consider yourself lucky. If it runs off quickly and little of it is absorbed by the soil, grading to reduce the slope may be necessary.

Grading sounds like a real engineering job, which it often is if done on a large area. However, the slope of a small garden, perhaps 30 feet across, should be easy to change so that runoff is slowed up and water penetrates readily.

The trick is to use "cut-equals-fill" techniques. If you want to change the grade ten inches, don't take all ten inches off the top side. Instead, remove five inches from the upper end of your garden and add it on the lower end. This sounds complicated, yet can be carried out over a weekend or two without too much work.

CORRECTING POOR DRAINAGE

If water from the upset barrel remains on the surface for several hours without soaking in, or if water stands there for several days after a spring rain, drainage is poor and must be improved. A basic principle is that water must have some place to go. No matter how well prepared soil may be, it can become waterlogged if no outlet is provided for excess moisture during spring or other periods when rainfall is heavy.

Check both absorption (by the upset barrel test just mentioned) and accumulation. The latter can be tested by digging a hole about 18 inches deep in spring and watching to see if water accumulates and stands in it following heavy rains. If so, then a drainage line of tile should be run to a lower point to take off excess moisture. If the garden soil is loose and friable, this line need not cross the garden at all, but can run from the lowest corner of the plot to some lower area of the property. On small city lots a drain into a storm sewer may be necessary, since few such lots are large enough to allow digging a line to a lower spot.

If no outlet can be provided, a dry well can be used as a partial answer to the drainage problem. A dry well must be big enough to take the surrounding soil's excess water until it can be lost by leaching, by evaporation or by transpiration. With a dry well there is no chance for run-off—the fourth way soils lose water—into a low area. One solution I have found for blotting up the water that gathers in a dry well is to plant a willow tree over the well. A willow will tolerate wet feet, and will transpire a barrel or more of water a day when in growth.

EROSION

Although erosion is a serious problem in farm soils, few gardens are large enough to consider this factor. When gardens must be made on slopes, common sense will dictate that the rows run along the slope rather than up and down, and that soil be made as absorptive as possible. Too, whenever a crop is harvested, some sort of a cover crop or mulch should go on as soon as possible to prevent wash-outs. Many kinds of effective soil-binding ground covers are available to gardeners whose landscapes contain slopes too steep (or otherwise unsuited) for grass.

TILLAGE AS A MOISTURE SAVER

The old reason given for cultivation was to maintain a dust mulch to "save moisture." We now know that *tillage wastes about as much moisture as it saves.* As crumbs of soil are kicked up by tillage equipment, all sides are exposed to air, allowing far more moisture to escape than if nothing were done. *The only saving by tillage comes from weed destruction.*

HIGH WATER TABLE

To overcome the problem of high water table, you can resort to an old Dutch trick—raised beds. Ever since tulips were first introduced into Holland in 1560, the Dutch have had to fight this problem and thus can teach us a trick or two.

First step is to wait until the water level is at its lowest point, usually late July or early August. Then scrape off the topsoil (which is usually quite rich in such spots) and pile it at one end of the property. Next, use any available non-rotting fill to build up the level about 12 inches. Do not use stiff clay or similar non-porous material, however. One of the best materials to use is ordinary steam cinders, available cheaply from power generating plants or from industrial plants with high pressure boilers. Sometimes the cinders can be had for the hauling. In this use, the cinders need not be weathered or washed: they will be under so much soil that sulfur compounds they contain will be well neutralized.

Then replace the topsoil, correcting pH if necessary and adding organic matter. The area should then be a foot higher than it was before, with an aeration layer under the surface to take care of excess moisture. If funds are limited, don't hurry the job. Do a little at a time but do it right. Piled black dirt won't be hurt if left for a year or more. You'll be surprised how many weeds will grow out of that pile: keep killing these as they appear and don't let them set seed.

Don't try to make a permanent lawn on such filled ground for a year at least: let it assume its final level first. It needs time to settle.

OVERCOMING SANDY SOIL PROBLEMS

The opposite condition to the one just mentioned is the sandy soil so well drained that even particles of organic matter are not held, but disappear along with the water. If the gardener tries to build up humus in such a soil, he is likely to be disappointed.

The remedy is costly in time and labor. It consists of removing the soil to a depth of 12 inches (for flower and vegetable gardens) and laying down a "floor" of tarpaper. Then a layer of organic matter is applied over the tarpaper, and the sand replaced.

After this treatment, organic matter and fertilizer will still be washed down by rain, but their descent will be halted by the tarpaper. Plant roots find stored food at this level and grow well. In a matter of five to six years, the paper rots out but by this time the mass of roots and accumulated organic matter are enough to act as a blotter for moisture and plant nutrients.

This system has worked for me, even in Florida, where every known plant food deficiency can be seen on sandy soils because nutrients disappear almost as soon as applied.

♦ ♦ ♦

CHAPTER DIGEST

Water and air comprise one of the leading partnerships in nature. The total success of Gardener's Loam depends largely on the harmonious relationship of these partners. Plants wilt if either one takes over the soil for a prolonged period—which explains the recommendation of a "moist, well-drained soil." Plants are made up almost entirely of materials obtained from water and air. And, since pla'nts can use only water-soluble nutrients, an artificial water supply should be assured as a supplement to rainfall.

Chapter 12

A Little Digging Goes a Long Way

How unfortunate that the term "in good tilth" is passing out of common use! Today it is seldom used to describe a state of well-being in soil—a "oneness" of mellow loam and the gardener's care lavished upon it.

In its place we now use more specific terms which accurately but unpoetically describe some fraction of soil condition—texture, structure, aeration and permeability.

Land in good tilth is well drained, yet holds its moisture tenaciously against the ravages of drought. Water seldom stands on the surface of Gardener's Loam for more than a minute or two before seeping deep into the intricate maze of passages between crumbs of clay, silt and organic matter. When such soil is dug or plowed the clods do not hang together in hard lumps but crumble to a loose, amorphous mold. Such a soil is rich in natural fertility—stored nutrients adsorbed on the clay and loam particles, as well as more tightly held in the humus that is so vital to good tilth.

One of the true delights of spring is the smell of such a soil being prepared for planting. As it is stirred by plow, tiller or spade, it emits a special fragrance which to a true gardener is the essence of the most wonderful time of the year—the awakening of living things to a new season of being. If you were to say that this fragrance reminds you of violets, you would be right, since the "top note" of aroma given off by damp earth contains at least two compounds also found in violet perfume.

Contrast a soil in good tilth with one in poor condition. The latter is hard to work. An old English phrase for poor soil is particularly expressive; it is called "four horse land," meaning that four horses are needed on the plow to turn the ground over in spring. When wet with winter snow and rain, such soil can be cut into slices like a pasty process-cheese, and it turns into hard ridges instead of crumbling. When four horse soil is dry, deep cracks furrow the surface and tillage tools can hardly break through. Unless worked at exactly the right time, it packs to brick-like hardness.

WHAT CONTRIBUTES TO GOOD TILTH

Good tilth is the product of many things. Perhaps the most important (except in muck-peat soils) is the use of generous amounts of organic matter. Another, described in the chapter on pH, is the lime-flocculation of clay particles which opens soil passages that allow the free movement of air and moisture. Proper provisions for drainage and aeration are also part of the complex of good tilth.

Even though all other provisions are made for improving the condition of soil, all can be undone if the soil is worked at the wrong time. Most garden soils (not sandy types, however) can be grievously compacted by just one cultivation if the job is done before the excess moisture of spring has drained away. Often it takes an entire season to bring the damaged soil back into a "good tilth" condition. For this reason you must learn to recognize the stage at which excess moisture has passed off so the soil can be dug or plowed without danger of compaction.

THE MUD PIE TEST

A quick, simple way to see the moisture condition of your soil is the mud pie test. Pick up a handful from the surface, selecting a spot that is neither wetter nor drier than the rest. Squeeze this soil between the hands and try to form it into a ball. If the soil is too wet, water may ooze out. Even if this does not happen the soil may still be too wet to work safely if it packs into a solid ball. Another "stop sign" is if the soil breaks into large, hard lumps. If, however, the soil is in condition to work you will not be able to press it into a dense ball. It will be loose and will crumble freely in your hands or when dropped.

Some soils, particularly those that contain too much clay, can become too dry. In such cases, a ball will not form when soil is pressed between the hands. The length of time it takes a normal soil to pass from the too-wet to the just-right stage is a rough measure of the quality of that soil.

SOIL AMENDMENT

Few homes are chosen primarily because they are on land where the soil is in good tilth. Often the owner does not know what kind of soil he has until months after he has moved in. In nine cases out of ten, it can stand improvement.

Most development (speculative) housing is on property from which all topsoil is stripped before building work begins. The thin layer replaced after each house is completed serves no purpose other than to camouflage the fact that the owner will have nothing to work with but subsoil. What is needed in such situations is soil conditioning. I hesitate to use that term because it has acquired a significance in the past few years which I do not wish to give it. Millions of Americans were made conscious of "soil conditioning" for the first time about 1952 when the chemical Krilium was introduced.

Although I want to give modern science its full due, I should like to point out that soil conditioning is as old as agriculture itself. Anyone who feels that soil may only be modified by the addition of certain modern chemicals will do well to refer to the works of such ancient Greek and Roman writers as Columella, Pliny and Aristotle. They knew nothing about chemical soil conditioning, of course, but they were familiar with the effects of treatment. They recommended lime and marl to loosen soil, as well as organic matter of both animal and plant origin.

POSITIVE AND NEGATIVE

Basically, the effect of all such substances, as well as modern chemical conditioners, is to supply positively charged particles which attract the negatively charged clay particles. When these combine they form clumps or floccules. The chemistry of this process is quite complex, involving both organic and inorganic colloids. Rather than attempt to go into every possible combination and how to treat it, let us return to our Chapter Two discussion of pH. By maintaining the pH of a soil between 6.0 and 6.9 (whether we add lime to a too-acid soil or sulfur to one that is too alkaline), we can solve most of the problems involved. The one major exception is in the case of soils where sodium colloids predominate—for example the drylands area of the Great Plains—but the addition of gypsum to such soils will convert the alkali carbonates into sulfates, reducing the harmful effects of sodium salts.

Wherever heavy clay exists, the most economical and effective way to condition soil is to add organic matter. Pound for pound it is not nearly so effective as modern chemicals, but dollar for dollar the cost is about one tenth that of chemical amendment. Where pH is so low that lime is needed, the use of ground limestone should also be a part of the conditioning. Organic matter, however, has advantages possessed neither by lime nor modern chemicals. (See related discussions in Chapter Eight.)

Organic matter improves tilth in every way. It provides a steady supply of fertility by the constant breaking down of plant and animal wastes, releasing the food elements they contain. Reduced to a more stable form—humus—it has been known to continue feeding for as long as half a century after application. Its spongelike structure blots up excess moisture and stores it against periods of drought. It forms crumbs with clay that open up passages in too-tight soils. Without generous supplies of organic matter, bacteria and fungi cannot thrive but when it is present they contribute their functions to good tilth.

PHYSICAL CONDITIONING

Any working of a (not-too-wet) soil tends to condition it by loosening it for deep root penetration, incorporating air and blending any surface organic matter into the lower layers. From the crooked stick of primitive man to the modern rotary tiller is a long, long way, yet both these implements had a common purpose—to condition soil and make it a better place for plants.

Except for tillage to kill weeds, the other benefits obtained from working the soil belong under the heading of soil conditioning. All these benefits result, of course, only when the gardener digs or plows at the proper time, as determined by the mud pie test, or by the experienced eye.

TRENCHING

Perhaps the ultimate in soil preparation and conditioning is the operation our British cousins call trenching. Trenching is sometimes confused with double digging, a somewhat less exacting and laborious operation. Trenching is an elaborate procedure during which the soil in the entire garden area is completely inverted, with the lower layer on top and the topsoil buried at least six inches beneath the surface. Underneath this "upside-down cake" the underlying subsoil is worked to an additional depth of several inches.

The operation begins with a trench dug to the depth of a standard garden spade entirely across one end of the garden (or lawn) area. The soil from this trench is wheeled to the far end of the area, where the work is to finish. Next the soil from the layer below the surface in the first trench, which may include some of the subsoil, is also dug out to another spade's depth and wheeled to form a pile alongside first. This leaves a trench, two spades deep, along one edge of the intended lawn or garden area.

Into the bottom of this trench a layer of organic matter is dumped and spread to a depth of two or three inches. Fertilizer is then sprinkled over this to help decompose the mass.

Because of the depth of this trench, it makes an excellent place to dispose of any weeds or other vegetable trash that may be around. Even if weed seeds germinate there is no chance that they will survive to reach the surface. The only thing to avoid are plants like Canada thistle and bindweed that have deep perennial roots which can grow through many inches of soil. Either fresh or composted organic matter can be used.

If the trenching is done in fall, it offers a good way to dispose of fallen leaves. Too, working during cool fall weather is much more pleasant than during the warm days of late spring and summer.

DEEP DOWN

Now dig in the organic matter in the trench bottom to the depth of a spade, mixing it well into the subsoil. If this is heavy clay, some ground limestone can be added to help loosen it. Any modification of pH should be made at this time: you will not have another chance at the subsoil for a long, long time. One job of trenching should last at least ten years.

If the soil is poorly drained, the time to make corrections is when the trench is open. To lay a drainage tile line, begin digging at the lowest point of the garden and lay the tile away from this trench to a lower spot so water that accumulates in the loosened soil has some place to go.

The next step is to dig a second trench alongside the first. The topsoil from the second trench goes in the bottom of the first, covering the organic matter. Next the lower layer from the second trench is placed on top of the topsoil in the first trench.

This operation, repeated across the garden, works the soil to a depth of three spades, or approximately 18 to 20 inches deep. It places rich soil and organic matter down deep, where the roots of plants can reach them. For a year or two, fertilizer applications to the area should be doubled, to make up for the decreased richness of the subsoil that is now the topsoil layer. Soon, however, as plant residues and roots are worked into this surface soil it improves in richness and tilth. If your subsoil is very poor, improve it before shoveling it into the preceding trench.

NOT ALWAYS ADVISABLE

Obviously, trenching is not always worth the time and effort involved. It would be completely wasted, for example, if only shallow-rooted crops such as petunias and lettuce were to be grown. In rich, deep, black prairie soils such as are found in parts of the Middle West, topsoil may extend down two or three feet, so that the soil dug out of the bottom of the trench would be just as rich as the top.

Certainly, trenching is not an operation for an older gardener or a man with a poor heart. It is hard work, and not to be undertaken lightly. However, rewards are high when the operation is needed and properly done. For example, it is ideal when a hedge is to be planted, in which case only two trenches need be dug.

DOUBLE DIGGING

The labor involved in true trenching has led to the development of a substitute operation called double digging. Here only a single-depth trench is opened and the earth wheeled to the finish line. Organic matter is worked into the bottom of the single-depth trench and topsoil from the second trench applied over this. Except for the wheeling of the soil from the first trench to the finish line, double digging actually requires no more physical effort than ordinary digging; in both methods, every clod should be turned completely over. With either trenching or double-digging, there is little tendency to develop a hardpan or "plowsole" deep in the soil because when the ground is worked in succeeding years, the spade or tiller will not penetrate to the depth previously reached.

MECHANICAL TILLAGE

Despite the saving in effort made possible by power-driven tillage equipment, I still like to dig by hand. There is something about this task which lifts it out of the class of drudgery, even though in turning over a thousand square feet of garden I may move several tons of soil. The smell of earth in good tilth, the sun and wind and the feeling of kinship with the world of plant life just cannot be duplicated by the chugging of a garden tractor.

Unfortunately, limitations of time and physical strength will not always permit us to use our muscles for soil preparation. With just so many hours in a weekend, we cannot afford to do a little at a time. Before we could finish the job the best time for seeding and planting would be past.

The gardener is, therefore, faced with the problem of selecting the most satisfactory form of tillage machinery, whether he buys it outright or hires his work done. Most present-day garden "plowing" is done by rotary tillers. These work on the principle of a revolving shaft to which are attached sharp tines that penetrate the soil as they make a complete revolution around the shaft. The tines tear out roots, trash and plant wastes, chewing them into small pieces and burying them in a loose, fluffy duff of soil. Any organic matter, fertilizer or soil conditioning material applied to the surface is thoroughly and uniformly mixed in.

Small home-sized power tiller units are available but are usually too low in power to do a good job of deep tilling. Six inches is about the maximum depth you should expect from these small units. Actually this is deep enough to loosen the soil for the roots of most garden plants, but not where large amounts of organic matter are to be incorporated. About eight inches is maximum for most larger units. Both sizes are adjustable so they can cultivate from a fraction of an inch in depth, down to their maximum depth.

Although great labor savers, rotary tillers are not ideal. One objection to the type with sharp tines is that it produces too fine a soil particle. Excessive tilling with this type of equipment breaks down the structure of the soil and brings on heavy crusting. Many home gardeners are disappointed when they find that the loose, fluffy loam of spring has turned to a crusted solid mass by midsummer, into which water penetrates with difficulty. Another result of too-fine a particle is that more organic matter is needed to improve tilth following the use of a tiller. Apparently many of the organic particles get coated with clay so thoroughly they cannot act as soil conditioners. Most modern machines now have a cutting-knife tine, set at an angle, which does not churn the soil to a fine dust.

Another drawback of rotary tillers is their tendency to build up a tillage pan—a hard, water-tight layer just below the loosened soil. I have taken a spade and removed the loose layer of soil right after tilling and found beneath it a layer of packed soil almost too firm to show a heel print.

The tendency to crust and pack can be overcome by supplying the soil with extra organic matter or by using a mechanical soil conditioner such as leached steam cinders, vermiculite or Perlite. Sand is not a good material to use: its aggregate-in-concrete effect is accentuated when in contact with fine clay particles. I estimate that between *33* and SO per cent more organic material is needed in a soil when a rotary tiller is used than when the same soil is plowed or hand-dug. Of course, when this extra material is supplied, the result is a rich, deep, mellow loam in perfect tilth.

The problem of a tillage pan is not quite as easy to solve. The ideal answer is to trench the entire area before a tiller is used, after which a pan may not build up for many years. The compacting effect can be delayed somewhat by changing the depth to which the tines penetrate each time the soil is worked. In farm practice, chisel plows are used to drive a sharp narrow point through the tillage pan and shatter it. To my knowledge, there is no available home garden version of the chisel plow. Some smart manufacturer of rotary tillers would do the gardening fraternity a favor if he would develop such a device that could be interchanged with the tines for use at least once a year. It would bring rotary tillage close to perfection.

MOULDBOARD PLOWS

I have always been thankful that I was born near open fields. Although our home was in a city of over 2,000,000 population, we were surrounded by farm land on three sides and each spring could watch sturdy brown teams pulling old-fashioned mouldboard plows through the rich prairie loam of our area.

The action of a mouldboard plow is nothing short of poetry in motion. It is not a simple knifelike edge, slicing its way through the soil. Instead, the furrow slice is cut loose by the sharp edge and shin of the plowshare and forced against the plow surface. It strikes at such an angle that it is at first crumbled and granulated, and then turned, inverting the soil and depositing it on top of trash and plant residues. If the physical condition of the earth is good, no other device can do a better job of granulation and covering.

Old Dobbin's hoofs were not very large and did not compact the soil to any extent. The same cannot be said for many tractors which are heavy enough to cause serious compaction. Some of the smaller riding tractors, which weigh less than a horse, are a good compromise. Their one weakness is that they often lack adequate power, but if used at a fairly slow rate and with not too large a plowing attachment, they do an excellent job.

CHAPTER DIGEST

Gardener's Loam and "good soil tilth" are synonymous. Achieving such mellow soil almost always requires some tillage. After testing (perhaps by the mud pie test) to determine whether the soil's moisture content is favorable, the gardener can use a manual or mechanical method to prepare the ground for planting. Trenching, double-digging, and rotary tilling are effective methods—and if carried out properly they need not involve burdensome labor.

Chapter 13

Special Soil Mixtures

PICK up any British gardening publication of the past two decades and chances are you will see something about John Innes Composts. Developed between 1934 and 1939 at the John Innes Horticultural Institution, these special mixtures of soil ingredients have been pretty well standardized as growing mediums for seedlings and pot plants. So sacred are they to gardeners in England (where the mixtures are sold pre-packaged) that I suspect my comments about them will earn me a disapproving look or two. In spite of the public adulation given these mixtures, I believe the specialists who developed them will agree with me that they were never intended to be the ultimate, perfect blends for growing a wide range of plants.

Reading between the lines, my guess is that what the scientists were really striving for were standardized, uniform growing mediums that would always respond in the same way. These were designed for scientific research, so the factor of soil could be considered an invariable in all tests. As can be appreciated, when a scientist tries to check differences in the qualities, functions or responses of plants, one thing he must have is a uniform environment.

John Innes Composts are nothing more nor less than standard soils for research work and should be considered in that light. That they work out well as seed growing and potting mediums is a happy by-product, which has led to a much wider use than I am sure was intended at first.

Here are the formulae for two of these special composts:

SEED SOWING COMPOST

3% parts (by volume) coarse sand;
3% parts (by volume) peat, and
7 parts (by volume) composted medium loam.

To each cubic yard of the above, add and mix in thoroughly two pounds of superphosphate (18 per cent phosphoric acid) and one pound of chalk (calcium carbonate).

POTTING COMPOST

2 parts (by volume) coarse sand;
3 parts (by volume) peat, and
7 parts (by volume) composted medium loam.

To each cubic yard of the above, thoroughly incorporate the following:

Two pounds hoof and horn meal (13 per cent nitrogen);
Two pounds superphosphate (18 per cent phosphoric acid);
One pound sulfate of potash (48 per cent potassium), and
One pound chalk (calcium carbonate).

There are several obvious disadvantages to such mixtures. Medium composted loam would not be a uniform product by any means. Workers at John Innes might use loam from the same field each time, but chances of others matching this in other locations would be rather remote. Coarse sand in one man's language might be something approaching gravel in another's. Some ingredients might be difficult to find: I had to buy chalk at drugstore prices to run tests on these composts. And most gardeners would find hoof and horn meal hard to obtain. Also, original John Innes formulae call for steaming the first part of each mixture before adding other ingredients, a difficult operation for home gardeners.

Another standardized growing medium on sale in England is made up of two parts (by volume) of peat, two parts fine vermiculite (equivalent to the size used as a plaster aggregate in this country) and two parts kaolin clay. To a bushel of this mixture a fertilizer is added (8 oz. in all) made up of two parts magnesium sulfate, two parts potassium nitrate, three parts ammonium sulfate and four parts superphosphate (all fertilizer ingredients are by weight).

IN SAND AND PEAT

A method of growing all kinds of plants in sand and peat was developed in the greenhouses of Vaughan's Seed Company, Western Springs, Illinois, and has been continued by Frank McFarland at Half Day, Illinois, following the razing of the Vaughan range several years ago. In this system, the greenhouse benches are packed with a mixture of sand and peat which serves largely as support for the plants; nutrient elements are provided by flooding the benches with fertilizer solutions. Frank McFarland uses nothing else to grow his superb greenhouse chrysanthemums. (He cuts a crop of blooms every day in the year on an exact schedule, and they command premium prices on the cut flower market.) This method of growing plants to maturity would be difficult for the amateur greenhouse owner, but is ideal for starting and temporarily growing seedlings, either in the house in a sunny window or in coldframes, hotbeds and home greenhouses. The following modifications have been worked out for amateur use:

Use clean (new or sterilized) flats, pots or greenhouse benches. The new "root-through" peat-and-fiber composition pots can be used without sterilization. Fill whatever containers you use with one of the following "soil" or growing mixtures:

(A) 50 per cent Swedish, German or Canadian peat, plus 50 per cent sharp sand
(B) 50 per cent Swedish, German or Canadian peat, plus 50 per cent horticultural-grade vermiculite (Terralite)
(C) 50 per cent Swedish, German or Canadian peat, plus 50 per cent Perlite

After filling the container with growing medium, soak with plain water; allow the soil mixture to settle before sowing seeds. After sowing, cover growing unit with one of the plastic bags used to cover freshly-pressed clothes or with other thin plastic film. Often, the container will not have to be watered again until seeds germinate. After germination, water once with a soluble complete fertilizer such as the following trade-name products: Rapid-Gro, Plant Marvel. Use one level teaspoonful to one quart of water.

THE U.C. SYSTEM

One of the most complete methods for using special soil mixes ever developed is described in the publication "The U.C. System for Producing Healthy Container-Grown Plants," by Dr. Kenneth Baker, available for $1 from the University of California, Los Angeles 24, California. The publication recommends a system of growing plants which gets around the defects of John Innes Composts and also describes methods for overcoming diseases, pests and other problems. While primarily for commercial growers, the U.C. system should be of great value to anyone working with the special problems involved in growing plants in containers.

As stated, it is almost always advisable to sterilize soil (and pots, etc.) before use. This is most commonly done by steam (heat) or by chemicals. With any of the several chemical sterilants now on the market, be sure to follow package directions exactly.

SPECIAL SOILS FOR ROSES

Fortunately, some of the furor over special soils for roses has died down. I can recall a time when mere mention of that subject was an invitation to bitter arguments.

At the moment, the cow-manure-and-clay school seems to have lost out completely. I have not seen this system of growing roses mentioned in any article for the past year. (At one time, at least 95 per cent of all articles on roses included an admonition that if you wanted to grow the Queen of Flowers, you'd better have clay soil and be prepared to beg, borrow or steal several yards of cow manure. If you didn't, you risked being boycotted by all right-thinking rose lovers.)

Cow manure lost out to ordinary fertilizers when that ambrosial product disappeared from within easy reach of city gardeners. Rose growers on or near farms still use it as one of their special privileges. I can't pretend that I am not envious, or that I scorn it. At the same time, I am not unaware of the fact that persistence of blackspot fungus in many a manure-fed garden can be traced directly to survival of spores in a cozy bed of damp cow manure over winter.

PERSISTENT CLAY

The preference for clay in rose beds has persisted longer. Even today, the notion that roses prefer clay pops up from time to time in print. An amusing item of contradictory advice appeared in a recent encyclopedic English book on roses. In one chapter the author advises against firm planting of rosebushes, while in another chapter he says he favors clay soil.

If truth be known, roses will survive in almost any soil, from a sandy loam to a stiff clay, so long as they have all the food and moisture they want. Actually I would say the lighter the soil the better the root growth. The most vigorous roses I've ever seen are volunteer Rugosas that stand eight feet high in a grove that covers half an acre. The plants have stems 2 inches through at the base. This grove is in pure sand at the edge of a swamp but is fed by runoff from a richly organic meadow higher up.

When we speak of roses, most of us mean the modern hybrid tea which, as one outstanding authority described it, "is a damned poor excuse for a shrub." We must remember that the rosebush of commerce is grown (grafted) on an understock which was selected as much for the convenience (ease of propagation) and profit of commercial growers as for its vigor and ability to recover after transplanting. The understock *Rosa multiflora japonica* has one weakness; it regenerates new roots so poorly after planting that sometimes a year or two is needed to allow it to make an adequate new root system. To illustrate: I dug up some rosebushes which had been planted in clay two years before. I found the bushes had made few roots and these few were stripped off in the digging operation. The same varieties planted in loose, friable Gardener's Loam not only grew plenty of new roots but made 25 per cent more top growth.

A FEW TOUGH PROBLEMS

There are very few soils that will not grow good roses. Thin whitish and gray clays found occasionally on older farmlands in the

East, pure sands without any organic matter, and the alkali soils of the West present problems too difficult for most gardeners to try to overcome.

Otherwise, any soil can be made suitable for roses. One proviso is to add all the organic matter you can afford, up to 25 per cent by volume. Provide good drainage and adjust pH to a reading between 6.0 and 6.9, and roses will grow.

One bit of nonsense to avoid with roses, unless time hangs heavily on your hands, is the old idea of digging out a pit 36 inches deep, laying down small rocks or broken bricks for drainage, adding a layer of organic matter and filling in with rich soil. I can't see any profit in such a deeply prepared pit for roses. Their roots are too feeble to take advantage of the improved soil depth; they probably would never get a chance to feed on that layer of organic matter buried 36 inches down. The 24-inch depth of double trenching should be adequate for the root growth of hybrid garden roses.

SOILS FOR ERICACEOUS PLANTS

Plants which prefer acid soils rarely need special soil treatment in areas where they grow naturally. When, however, the gardener in alkaline soil areas of the Middle West or California (to cite just two places) decides he must have azaleas, rhododendrons, blueberries or heather, a very real problem arises.

True, a soil pH as high as 6.9 can be pulled down with sulfur to 5.0 to enable such plants to survive. But maintaining such an acid soil in an alkaline area is often another matter. Surrounding soil will continue to be alkaline in reaction, and unless the site selected is on higher ground than the rest of the area, water runoff draining into the treated soil will bring in alkalinity to undo the gardener's efforts. Domestic tap water will usually be alkaline with a pH as high as the native soil or higher. This is particularly true in limestone country where ground water filters through limestone strata.

Among the worst offenders are earthworms (see Chapter Ten). They prefer an alkaline soil or at least one less acid than will support ericaceous plants. Even though the native alkaline soil is removed to a depth of two or three feet and replaced with earth high in acidifying materials, earthworms will continue to burrow through this to reach the surface. Their burrows will be lined with limey slime brought from lower in the subsoil. Since most soils for ericaceous plants are high in organic matter, this helps feed the worms, which will pull half-decayed leaves, grass and other vegetation down into their burrows and mix it with limey soil to help digest it. I have seen a specially prepared area of rich acid soil ruined in two years by these pests.

The answer to earthworms is to dig out the pit to a depth of three feet and sprinkle chlordane over the bottom before refilling with acidified soil.

To counteract alkaline run-off into acidified soil, a ring or band of dusting sulfur perhaps a foot wide can be laid down around the treated area; drainage water must run through this sulfur strip.

Domestic water does not usually contain very much suspended matter, so if it is alkaline the amount of acidifying material needed to neutralize it is relatively small. Two ounces of sulfuric acid to 100 gallons of water is usually enough. If the planting is too large to be watered out of a barrel of treated water, there are devices which attach to the end of a hose; they withdraw a certain amount of sulfur solution out of a special container and mix it with tap water passing through the hose. Working out proportions to deliver two ounces of acid in each 100 gallons of water is a problem in simple arithmetic, once you know the proportioning ratio of the hose device.

Instead of liquid acid you can use a solution of one pound of ammonium sulfate or two pounds of ferrous sulfate to 100 gallons of water. The latter also supplies iron, an element often lacking in acid soils. (Used in this way, ferrous ammonium sulfate is not harmful, since the direct-nitrogen-fixing bacteria which it suppresses are not active in acid soils.)

Regardless of the chemical you use, check the water coming out of the hose; be sure (when pressure is full) that it checks at or below the pH desired. Always use the same pressure, since a change may change the ratio.

ASPARAGUS SOILS

Not long ago I read a book which offered elaborate instructions for making an asparagus bed. The soil was to be dug out to a depth of two feet, then broken brick, cinders or other drainage was to be laid down, followed by an organic-rich soil mixture to fill the excavation. This was to be allowed to settle, after which trenches 12 inches deep were to be dug for planting.

I am all for deep working of soil if it will be occupied by the same plants for ten to twenty years or more, as an asparagus bed well may be, and if the deep digging will return adequate plant-growth dividends. But asparagus will grow well in any ordinarily prepared garden soil.

Planting 12 inches deep is a waste of time for the asparagus crop and merely delays by at least a week the appearance of the first spears of the season, which, to my taste, are the best of the crop. No matter how soil is prepared, set crown tips not more than 2 inches down. We no longer want to grow blanched asparagus spears through six inches of soil. We no longer want to run cultivating equipment right over the crowns: today we use chemical weed killers. As for soil, any directions previously given for Gardener's Loam will produce a soil amply rich for this crop. Some of the best-flavored asparagus I ever ate came from a prairie which hadn't been plowed or manured for 30 years; in fact, the plants were growing wild all over the field.

CHAPTER DIGEST

Sometimes a need arises for a growing medium with some particular qualities—whether the material is to be used for garden or indoor plants. Among the special cultural compounds for container-grown plants are the John Innes Composts of English fame, while peat and sand mixtures (supplied with liquid nutrients) are used successfully by American growers. In the garden, of course, different problems surround the creation and maintenance of special soil mixtures or conditions. The pros and cons of soils for roses and acid-loving plants are discussed in helpful terms.

Chapter 14

Soil-Borne Plant Diseases

I WISH I could draw a clear-cut, one-solution picture of plant diseases; if only organocultists were right and all soil-borne diseases of plants—caused by bacteria, viruses and fungi—could be eliminated simply by not using chemical (inorganic) fertilizers! Unfortunately, the answer is not that simple.

Feeding practices do have definite effects on many diseases—sometimes causing them and sometimes preventing them. In the U.S.D.A. Yearbook of Agriculture for 1953, Dr. George L. McNew cites a most interesting example of confused effects. He describes wheat grown on moderately fertile soil and fed with an extra supply of nitrogen. This special feeding helped the wheat escape seedling diseases but made it more susceptible to Pythium root rot; protected it against "take all" disease but made the plants more subject to leaf rust and mildew. If, instead of an extra supply of nitrogen, extra phosphorus and potash had been used, a different series of effects and diseases would have resulted.

An application of manure to a poor soil in Arkansas might protect cotton against wilt by supplying nitrogen and potash, yet this same application of manure made on nitrogen-rich soil in the Egyptian Delta of the Nile would encourage wilt in cotton.

A LOT OF DIFFERENCE

A similar case of "different places-different diseases" is that of the use of sewerage sludge in California to cure a certain turf disease. But in my own work in Illinois, the snow mold disease was far more prevalent in turf fed with this same organic fertilizer.

Potato scab, a soil-borne disease, is much more severe in alkaline

soils. It can be prevented by the use of fertilizers and soil treatments that bring pH so low that the scab organism cannot grow. The reverse is true of wilt and club root diseases of cabbage, which is made worse by acid soil; the use of alkaline materials helps control these diseases. (For a more complete discussion of diseases, see *Plant Disease Handbook* by Cynthia Westcott, published by D. Van Nostrand Co.)

At the U.S.D.A.'s research station in Beltsville, Maryland, Drs. McClelland and Stuart proved that gladiolus diseases were much more severe when organic fertilizers were used than when only chemical plant foods were used. To cite an opposite, the use of organic matter around pineapple plants in Hawaii saved them from injury by a soil fungus. The plowed-in organic matter (various waste products from sugar refining) stimulated organisms that used up excess nitrogen, thus preventing Pythium fungus from propagating rapidly.

IN THE DIET

In all disease cases mentioned, the cause was found to be an imbalance of nutrition. It may have been too much nitrogen with too little phosphorus to balance it, or too little of all elements needed to produce a strong, healthy, disease-resistant plant, or a deficiency of some minor element. In some cases, it made little difference whether missing elements were supplied from chemical or organic sources. In others, existence of starches and sugars in organic matter provided food for fungi that caused a particular disease.

Again, an organic fertilizer might show better response because it is more complete, or contains an element missing from chemical plant foods. When no specific organism can be found that causes disease, full nutrition may be the remedy.

Gardener's Loam, with its complete supply of every element needed by plants, is the answer to many plant diseases,

FALL CLEANUP

Many garden experts talk about fall cleanup in much the same way that a dentist tells you to brush your teeth three times a day. He knows you won't take time to do so, but he's done his duty.

This cleanup recommendation has been echoed and re-echoed until it has lost most of its effect. In the past I have neglected fall cleanup, and four years out of five it made little difference in the amount of disease in my garden. In the fifth year, however, I was usually punished for my negligence, doubled and redoubled. The fact is that except for surface diseases which are carried by insects, such as aster yellows and virus diseases of some plants (carried by aphids and leaf hoppers from sources of infection outside your property), sanitation *can* prevent disease. The fall cleanup must not, however, be a perfunctory ritual. It calls for cutting off every standing plant about a quarter of an inch below the surface, removing a spoonful of soil as well as the stems. This is tossed in a waiting wheelbarrow.

Fall is a good time to start new compost piles (see Chapter Eight), "seeding" each new pile with bacteria-rich leftover material from an old pile. This old compost forms the foundation on which fresh garden debris is laid to form the first layer of the pile, unless the autumn leaf crop has already been added. Be sure that any plant wastes that might contain disease spores or insect eggs are buried deeply in the pile: they should not be closer than 12 inches to any exposed surface, for they must be subjected to the heat of fermentation. Add a good mixed fertilizer as well as some extra sugar or starch if possible (a good place to dispose of spoiled jellies, jams, wormy flour, and so on).

There are a number of soil-borne diseases caused by specific organisms that can survive for years in the garden. But they are not likely to attack plants well grown in Gardener's Loam in a plot open to sun and air circulation. However, it is well to keep an eye open for them—particularly the following:

ON FLOWERING PLANTS

Stem Rust: Caused by a *Phytophthera* organism, it girdles the stem at ground level, after which the plant wilts and dies. Rust can be controlled in greenhouse soils only by steam sterilization of the soil. Outdoors it is not too common, which is fortunate, for there is no practical control. The classic snapdragon rust does not invade the soil; it is best controlled by growing rust-resistant varieties.

Phyllosticta Blight: Like the preceding, it girdles stems at ground level if plants are young. On older plants, cream-colored dots enlarge to dark brown or black-zoned patches. Spraying with Phaltan every 10 days during the growing season will control it. It occurs largely on outdoor snaps.

Botrytis Blight: Caused by *Botrytis cinerea,** an aggressive fungus which attacks hundreds of different species of plants. It is the cause of "tulip fire" and browned, shriveled peony buds, to name just two of the familiar injuries (see later entries in this chapter). Burn infected plants. Spray with a modern fungicide.

Fusariutn Wilt: This is one of the "classic" diseases (so called by plant pathologists), well known, widely distributed and difficult to control. It will survive for years and infest asters, chrysanthemums and many other plant species. Seedlings damp off and at this stage the infection is hard to tell from *Rhizoctonia.* Mature plants may wilt suddenly. There are so-called wilt-resistant varieties but, in my experience, these are of little value in the Middle West and South because soil temperatures go too high. In California and other sections where nights are cool, wilt-resistant varieties do well.

Rhizoctonia solani: This is a confusing fungus because it has many forms, often called by different names in the perfect and imperfect stages. It is one of the major causes of damping-off of seedlings. Seeds may be attacked before they sprout. I have, for example, seen a row of mixed sweet peas, in which *Rhizoctonia* killed off all white-seeded forms but left black-seeded varieties intact 1 At other

*** Vintners in Germany and France, far from fearing *Botrytis cinerea* as a disease, welcome its presence on their ripe grapes. Infested grapes turn a hoary gray as the fungus creeps across the berries. Before they are harvested, they lose more than half their moisture and begin to shrivel. Vineyard owners prize these moldy berries above all the rest of their harvest. For some strange reason, although the mycelium penetrates the skin, it does not change the flavor. It condenses the juice until instead of the usual 15 to 25 per cent of sugar, the juice has become so sweet that readings of 55 to 60 per cent sugar are not unusual.**

The French phrase for bunches infected in this way is *pourriture noble,* while in Germany the name for it is *Edelfaule.* Both phrases mean "noble rot." Wines made with these condensed grapes develop 15 to 17 per cent alcohol without fortification, yet retain natural sugars. These are the great Sauternes and Rhinewines that are so rich they are usually drunk as dessert wines. If you are fortunate enough to drink a Chateau dTTquem, Chateau La Tour Blanche or a Rhinewine labeled Spatlese, Auslese or Beerenauslese (perhaps even that rare Johannisberger Kabinett), bow your head to *Botrytis cinerea* as you sip 1

times, it kills the seedling after it has formed its first true leaves, rotting it off at the soil line.

Best defense against *Rhizoctonia* is the use of a sterile growing medium, such as vermiculite, Per lite or sphagnum moss (florists often use steam-sterilized soil, but this is beyond the reach of most amateurs). Such treatment does *not,* however, completely avoid infection if tools and flats or pots are not sterilized or if they are set on dirty benches.

Seed treatment with commercially available chemicals such as Spergon, Panodrench, Arasan, Semesan and Cuprocide is so cheap that no gardener should ever plant untreated seed.

Other Damping-ojJ Organisms: Many fungi that live in a soil on organic matter, such as saprophytes (living off dead matter), will turn parasitic when tender seedlings come in contact with them. As indicated, the answer lies in clean soil and chemical soil treatment.

Petal Blight: Here is another "classic" disease which causes tremendous damage, especially to azaleas. Several plant pathologists worked on it, but it was not until Dr. Cynthia Westcott discovered, in 1945, that Dithane-D-14 was a specific control, that it could be kept in check. Azalea petal blight is mentioned here because the resting stage survives on the soil under the plants. Here it can be killed by calcium cyanamide. Unfortunately, this is of little value except in protected, isolated gardens where a single plant is infected. The spores float for miles to infect blossoms, which turn a watery brown.

Wilt Diseases: Especially bad on carnations, wilt diseases occasionally do invade the garden if outdoor varieties are propagated in the same house as greenhouse carnations. The only answer is to destroy the plants and refrain from growing this flower for three years. In the greenhouse, an elaborate ritual of culturing will produce clean stock which can only be kept clean if hospital-like practices are followed.

Botrytis Blight: This disease is the bane of many plants, including some types of lilies; it often kills *L. candidum* (Madonna lily) bulbs in the soil. It is, however, spread above ground and comes within the scope of this soil disease discussion only because it moves down the stem and under the soil. Other lilies are less drastically affected. Spots are at first small purplish or brownish, fading to yellow. Leaf may finally collapse. Spraying with Bordeaux mixture is the old-time remedy. The newer Phaltan seems to work as well in many cases. When tulips are infected with *Botrytis Blight* (tulip fire), small yellow or brown dots enlarge and cover the entire plant, flower and all. Leaves and petals look as though scorched by fire. Infected bulbs may carry the disease. Imported Dutch bulbs are reasonably clean. Spraying the shoots as they break through the ground with Fermate (four sprays, a week apart, starting when shoots are 3 inches tall) will usually give good control.

Basal Rot: A serious disease of narcissus: it is encouraged by nematodes that open a path for a *Fusarium* fungus. Buying bulbs from a reliable source is about the home gardener's only control.

VEGETABLES

Except for a condition known as curly top or shoe string top in tomatoes, few disease ills beset the plants in the home vegetable garden. If you are in cabbage yellows country, the resistant varieties will give you a crop in spite of the fungus. Commercial vegetable growers are plagued with a number of serious diseases, due to the concentration of vast numbers of plants of a single crop in a given area.

Clean seed is important. Buy seed in packets from a reliable source (avoid bulk seeds sold out of jars or bins). Treat with one of the commercial seed protectant chemicals before sowing.

If a good fall cleanup program is followed, clean seed sown in Gardener's Loam should give practically no trouble.

CHAPTER DIGEST

Several soil factors bear significantly on many of the most common plant diseases (caused by bacteria, fungi and viruses). The condition of the soil (pH, tilth, and so forth), and the kinds and amounts of fertilizers used, are among the major in-ground influences. Garden sanitation is an important preventive. A number of serious soil-borne plant diseases—their characteristics and some effective control measures—are discussed.

Chapter 15

Harmful Soil Insects and Other Pests

ANY natural, uncultivated field or forest soil without insects living in it would probably be poor. However, a carefully tended Gardener's Loam without insects and other harmful pests (or at least a minimum population of them) is not only possible but desirable.

Discovery of chlorinated hydrocarbons of high potency (beginning with D.D.T. during World War II) gave us weapons of amazing efficiency to use against harmful soil-inhabiting pests. Properly used (they *can be* abused) these are not only safe to handle but endure for years in soil. No gardener can really appreciate their value until he has seen a lawn completely freed of grubs for four or five years with a single application of a chemical such as chlordane.

Such potency against insects naturally raises fears of the effects of these chemicals on human beings and animals. Oddly enough, most insecticide materials of this type are actually less dangerous to higher animals than are older chemicals they replaced. A case in point is chlordane which took the place of lead arsenate as a turf treatment against grubs. Chlordane is so safe that it is approved for use (with only normal caution) as a household insecticide, for spraying living quarters, basements, kitchens and other areas where the old lead arsenate would be highly dangerous. Arsenate of lead has been responsible for many deaths: I have yet to hear of a single person being killed by chlordane.

Other equally effective chemicals are available for use on insect species not too easily killed with chlordane. Most of these materials are rather specific in their action and not as useful as chlordane for a general insect-proofing treatment.

INSECTICIDE RESIDUES

Buildup of harmful insecticide residues in soil is possible, even though the material used is quite safe to apply. Such accumulations are almost always the result of misuse and failure to follow directions.

Insecticide residues harmful to plants are not new; injurious effects of copper following regular use of Bordeaux mixture on grapevines in France were reported in the nineteenth century. One of the earliest such reports in America goes back to 1908—it dealt with arsenate of lead accumulation in an apple orchard.

Soil type has a great deal to do with harmful effects of such residues. For example, the home owner who has established a lawn after years of work on a sandy loam, only to find it infested with grubs, would do well to think twice before using arsenate of lead or calcium arsenate as a grub control.

Several years ago, hi connection with experimental work on calcium arsenate as a long-term crabgrass control, I went back over the literature to discover what harmful effects calcium arsenate might have had on grasses when used in heavy applications. I found that grass was amazingly tolerant, except on sandy soils. On clays and clay loams, cereal-type grasses and others were not injured at rates that ran into thousands of pounds of calcium arsenate per acre, applied over a two- or three-year period. Soy beans withstood doses of as high as 30 pounds of actual D.D.T. per thousand square feet on clay, but were injured on sandy soils by doses as low as 8 pounds per thousand square feet. If available iron was added to the soil, injury on sandy loam did not show up at calcium arsenate rates lower than 15 pounds per thousand square feet. In New Jersey, lima bean, snap bean and turnip seedlings were killed by applications of 30 pounds per thousand square feet. The few seedlings that did survive, however, were able to grow into normal plants once their roots penetrated past the soil layer on which the calcium arsenate had become fixed.

POTENT PAIR

Today, of older materials used for soil treatment, only calcium arsenate and lead arsenate are of much importance. Both are being used as pre-emergence crabgrass controls at rates of about 10 pounds to a thousand square feet of lawn area. When applied to lawns, these two chemicals form a layer of treated soil in which germinating crabgrass seedlings cannot survive. They work by substituting for phosphorus, starving the seedling for that element.

The correction of arsenate toxicity is obvious: heavy applications of superphosphate will undo practically any case of toxic soil due to either of these chemicals.

Each year sees a decrease in reports of lead and copper toxicity as these older insecticides are dropped from modern spray schedules. Today, our concern is with residues of chlorinated hydrocarbons such as D.D.T. and chlordane. A further problem is that of residues from chemical weed killers, which is covered separately in Chapter Sixteen.

THE BIG ONE

The most serious residual problem likely to be experienced by home gardeners is from D.D.T. used for soil treatment. Grasses are highly tolerant: doses of as high as 30 pounds to a thousand square feet have shown no injury. Theoretically, since D.D.T. is used largely to grub-proof lawns, there should be no human hazards from overdoses. But, of course, grass plots may not always remain as grass plots; if they are converted vegetable gardens, the D.D.T. overdose hazard becomes real.

In my own case, I converted my vegetable garden into a lawn area when we acquired a summer home. However, I can see a time when, with children grown and married, we may give up summer jaunts and resume vegetable gardening. If you, too, foresee the possibility that food crops may someday be grown on present lawn areas, the use of large doses of D.D.T. for grub-proofing and so forth would seem unwise. On lawn areas which are not so likely to be plowed up and converted, this chemical (which costs much less than chlordane) is the preferred treatment for many soil insects.

Except where cost is a factor, as when a large lawn must be treated, chlordane is the most satisfactory soil pest control for amateur use.

Benzine hexachloride, called BHC for short, is widely used on farm crops. It has no place in the home garden. Less than a pound to 1,000 square feet will seriously injure many plants. It contaminates all root crops so strongly that they cannot be eaten.

SOIL-INHABITING INSECTS

Many insects spend all or part of their life cycle underground but do not properly come within the scope of this chapter. For example, the tomato hornworm, a thick, ugly green insect familiar to anyone who grows tomatoes, does go underground to pupate but since it does not feed there, and cannot be controlled by soil treatment, it is not included in my discussion of soil-inhabiting insects. Proper to this chapter is the May beetle or June bug; it spends three years underground, feeding and injuring plants, during which period it can be controlled with soil insecticides.

The best way to attack insects that spend part of their life cycles underground and cannot be reached by chemicals is to dig or plow all areas not in use as soon as possible in fall, leaving clods and lumps rather than raking the areas to a level surface. If you delay this job until killing frosts have occurred, it will not be too effective. Most insects have laid their eggs by mid-September in the North. I find that control is much more complete if the soil is turned twice, or, better, three times *before* the first crusting by frost occurs. This exposes insect pests, as well as weed seeds, to migrating fall birds, many of which leave the North before frost comes. Fall rains wash out buried eggs, exposing them to frost action and to birds that remain over winter.

PESTS CONTROLLED IN THE SOIL

Ants: Treatment of soil with chlordane disposes of many ant species annoying in the garden. Soil under peonies especially should receive this attention to kill ants that take honeydew from the buds. If ant nests can be located, dusting or spraying with chlordane will mean much better control, as this destroys young ants which might otherwise not be reached. When ants march in from surrounding woods or from other properties, use sweetened ant poisons or prepared baits.

White Grubs: Many species invade gardens and lawns. Larvae or grubs of the May beetle or June bug are particularly destructive.

The grubs spend parts of three years underground. Eggs are deposited in June and hatch a month later into larvae that feed on decaying vegetable matter and on roots of plants. They continue feeding through a second year, during which they do severe damage to lawns. Early in spring of their third year, they stop feeding and turn into adult beetles, emerging to begin the life cycle over again.

Application of chlordane or calcium arsenate will destroy the first and second broods of grubs, but may not show much effect on the brood that is about to emerge as adult beetles in May and June. This misleads those who have used chlordane; they think it is of no value. **However, for at least four years following date of treatment, no** living grubs will be found, once the spring brood has emerged.

In lawns, grub injury may be limited (a paler green color in patches may indicate loss of roots and poor nutrition due to feeding of second-year brood), or may be severe. When severe, the roots often are cut off just below the surface so sod can be rolled back like a carpet, exposing feeding grubs underneath. In less severe cases, removing a square foot or two of light, weak sod and digging into the soil should be enough to reveal whether the dirty-white curled larvae with blackish heads are present.

Japanese Beetle: These differ from June bugs in their life cycle, but, like them, do severe damage by eating at plant roots when underground. Japanese beetle grubs spend 10 months in larvae form, surviving one winter. In late May or early June the grubs stop feeding and pupate, emerging as adult beetles. They live for little over a month, feeding on leaves and flowers and laying eggs, usually selecting lawns or other grass areas for the latter purpose. Late-hatched adults may survive as late as early October.

Although these beetles are voracious eaters of prized flowers and foliage, we are concerned with the underground, root-eating period of their life cycle, which begins when the young hatch from eggs during late summer. By fall the grubs are half grown. They feed on roots until checked by cold, resuming again in spring. D.D.T. treatment will control grubs in soils for up to six years, while chlordane will do so for at least four years. Even longer effectiveness is provided by a biological control measure—the introduction into the lawn of the so-called milky disease. Prepared spore cultures are on the market.

Termites: Although these pests are usually considered destructive only to foundations of houses, they can become serious pests in soils containing any amount of partially decayed wood or other woody matter. They work beneath the surface and burrow inside stems and are not detected until dying plants lead the gardener to investigate. They are much more troublesome where organic fertilizers are used.

To control, remove any wooden stakes, edgings or other sources of cellulose, then dose soil with chlordane. Where termites are active, be sure to protect fences, stakes and other wood used in gardens with a wood preservative such as copper naphthanate or pentachlorophenol. Avoid using organic fertilizers.

Slugs and Snails: Baits containing metaldehyde will lure these pests out of their holes to feed and die. Remove flat stones or shingles under which they hide. Dusting paths and walks with hydrated lime or dry wood ashes often traps them and dehydrates them. Sometimes dabs of either material placed on the soil and covered with a shingle will trap them by the dozens.

Millipedes, Sowbugs and Pillbugs: Chiefly these are signs of poor housekeeping in greenhouses: remove all organic matter and dust under benches with chlordane. (Dusting with chlordane is also the outdoor remedy.)

Sweet Potato Weevil: Grubs burrow through sweet potato roots and stems. Apply one pound of 10 per cent D.D.T. dust to 1,500 square feet of garden or use 20 ounces of SO per cent wettable D.D.T. to a gallon and a half of water, applying this to 1,000 square feet.

Wireworms: Hard, buff or ecru-colored segmented worms are very destructive to root crops. Same treatment used for sweet potato weevil will control wire worms.

RELATIVE IMPORTANCE

Many of the more destructive insects are sheltered and fed by partially-decayed organic matter. This is one reason why composting plant wastes in a compost pile is better practice than applying them to soil and plowing under. In the compost pile, insect control measures can be more easily taken. The use of calcium cyanamid in the last turning of the pile will check breakdown temporarily, but will get rid of grubs.

Earthworms (see Chapter Ten) will be killed by most of the previously mentioned treatments.

MANY MOLES

Moles are of minor importance except where they are abundant, when they can be a real nuisance. You may be surprised to learn that moles do *not* eat roots, tulip bulbs, and so on, although often blamed for disappearance of these plant parts. Moles do approach or touch underground parts of plants as they burrow through soil looking for insects on which they feed. In doing so, they often open a passageway for mice or ground squirrels which do eat bulbs.

Because they feed solely on insects and other soil animal life, moles can best be driven out of a lawn or garden by treating the soil with insecticides such as chlordane, dieldrin, calcium arsenate, arsenate of lead, or DDT. With their natural foods eliminated, moles will quit burrowing through the treated soil.

NEMATODES

The tiny (sometimes microscopic) thread-like creatures called eelworms or nematodes (nemas to the scientist) are the most mysterious and least understood of all creatures inhabiting the soil. Zoologists regard them as a race apart from other worm-like soil dwellers. They were known to early microscope workers, but considered of no economic importance and generally ignored until about 30 years ago.

Some animal-parasitic nematodes are beneficial, but practically all plant-parasitic species (both leaf and root nematodes) are injurious. And contrary to common opinion, most nematodes are not killed by freezing. There are nearly 10,000 known species of nematodes, several hundred of which are known to attack plants. (Much work is yet to be done in classification.) Because of the ease with which these creatures mutate and produce new forms, the nematode threat is enlarging.

The first recognized soil-pest menace to plant life in America (or at least the first considered important by Federal authorities) was the importation of nematode-infested narcissus bulbs from Europe in 1926. In that same year a disease called spreading decline was classified as a serious threat to citrus grooves in Florida, but was not associated with nematodes at the time.

All during the 1930's the science of nematology was relatively neglected. Then in 1941 the discovery of a full-scale infestation of a species called golden nematode on Long Island set off a furious "crash program" to bring our knowledge of nematology into line with the threat presented by these creatures. The golden nematode, known to be a dangerous pest of potatoes, is one of the cyst-forming species, which possesses a peculiar type of female immortality. Older females do not die but form an egg-like cyst which can remain dormant for years. This cyst then regenerates when conditions are favorable. Once in a soil, cysts can survive for decades, without any outside source of food or water. Years after the soil has been fumigated and treated with nematocides, cysts may still regenerate, so a constant watch and recheck of the area must go on.

In 1953, the serious spreading decline of Florida citrus was traced to the burrowing nematode as the carrier. Since that time, nearly $3,000,000 has been spent in an effort to eradicate this pest from citrus groves, but the end is not yet in sight.

IN THE GARDEN

We now know that every commonly-grown fruit and nut crop is attacked by one or more nematode species. Vegetable crops are parsitized regularly, even in the North, and damage done to these food crops is estimated at over $100,000,000. It is on these crops that the home gardener is most likely to encounter nematodes. They form knots or lumps on the roots of many plants, most conspicuously on carrots. Other crops are attacked internally without visible symptoms other than a decline in vigor and productivity. Tomatoes, beans, okra and many vine crops can drop as much as 50 per cent in productivity without any sure sign of infestation. Foliar symptoms on many plants, such as premature dropping of leaves, stunting and yellowing are not clear-cut enough to mark them as different from the symptoms caused by certain nutritional or insect disorders.

Ornamentals are also attacked. Over 600 different species of trees, shrubs, flowers and lawn grasses are known to attract nematodes. The root-knot nematode alone attacks more than 500 different species, causing severe loss of plant vigor. One of the worst in its effect is the foliar nematode that attacks chrysanthemums in the greenhouse bench. It is able to move up stems and across leaves on the film of water that forms on the leaf by condensation. When it reaches a stomatal opening, it penetrates into the heart of the leaf where it is all but immune to any form of control.

During the past two years many members of the American Rose Society have become increasingly aware of the damage done by nematodes, and numerous articles on these pests have appeared in the Society's journal.

WHAT CAN BE DONE?

The nematologist in one southern state told me recently that he had never checked a garden soil without finding one or more nematode species parasitic on plants. He was reasonably sure that no such thing as a nematode-clean soil existed in his state. Most scientists feel that once a soil has become infested, complete eradication is almost an impossibility, even if only non-cyst-forming types are involved.

Since eradication is impractical the one course open to us is to reduce the population to a point where plants can survive and grow reasonably well in spite of some infestation. The first step in such a program should be exclusion. Since nematodes are so widely distributed throughout the United States, this might seem like locking the barn door after the horse is gone. However, the introduction of new and more virulent species is always a possibility. I feel certain that the use of southern-grown tomato and cabbage plants in the North has been a means of annually reinfesting many growing fields with nematode species which do not ordinarily survive northern winters.

A case in point regarding infestation of soil by introducing plants is that of *Radopholus similis,* the burrowing nematode which causes the spreading decline of citrus. This nema does not survive in the North, but is known to infest more than 100 ornamentals, many of them house plants which are shipped to northern markets from Florida. This pest is showing up in greenhouses in the North, apparently brought in on Florida foliage plant shipments.

CHEMICAL TREATMENT

Formerly we were limited to controls which could be used only when the soil was not occupied by living plants. These included applications of chloropicrin, dichloropropene, ethylene dibromide and similar volatile chemicals. Newer chemicals of this type include Dow Telone, Shell D-D, Vapam and Mylone. These are employed on greenhouse and coldframe soil used for propagating purposes (where the chemicals can kill 100 per cent of all nematodes) and for treating rows in the nursery (where complete control is not achieved, but nematodes are set back sufficiently so plants can make near-normal growth).

There is another chemical, scientifically designated as 1,2-dibromo-3-chloropropane, and sold under the trade names Nemagon and Fumazone, which can be used around living plants without injuring them. Also, certain phosphate insecticides are available that can be applied to the soil for absorption by the plant to kill internal nematodes. To date, however, chemical control is not 100 per cent effective.

NATURAL CONTROLS

Several years ago, I was at the U.S.D.A. station at Beltsville, calling on Dr. Charles Wechsler, a root-rot specialist. He had been studying nematodes as carriers of disease organisms, and at the moment happened to have a culture which contained both nematodes and a ring fungus. He asked me to look in the microscope and observe the natural death of a nematode. As the nema poked its way into the odd ring-shaped organ on the fungus, the ring closed, trapping its victim so it could not escape. This was my first introduction to the fungus enemies of nematodes, which I discovered were fairly numerous. Some, like the specimen I saw, actually close on the body of the nematode. Others work like an eel-pot; these have a ring that allows the victim to enter with its head, and then trap it so it cannot move either forward or backward.

Other fungus species have been aptly named Lethal Lollipops. These have a ball-like structure covered with a sticky substance on which the nematode is caught like a fly on sticky flypaper.

These various fungi exist in all soils high in organic matter. They tend to die out, however, if moisture content of soil fluctuates up and down; they prefer a uniformly moist home. Their action against nematodes comes under the heading of biological control.

I have discussed with several nematologists the possibility of controlling nematodes by encouraging the ring and lollipop fungi. The consensus is that while these fungi are useful in keeping down the population, they tend to be self-limiting, since when the population is reduced only partially, the fungi tend to die out. Apparently, they depend upon nematodes' bungling into their traps, and if not enough victims are around, they starve.

There are predatory nematodes too; they feed on their plant-eating nematode relatives, but cannot multiply to a point where they will effect full control. In other words, with nature's help, science is fighting a holding battle while working toward a total solution.

CHAPTER DIGEST

Modern chemicals have given the gardener some highly potent weapons for his endless campaign against injurious soil-inhabiting insects and various other creatures. However, there is another side to the coin: these chemicals have harmful effects if misused. Where possible, natural (biological) control measures should be employed in partnership with chemical warfare. The discussion of controls for specific enemies gives greatest emphasis to nematodes, for they pose a grave and too-little-understood threat to almost all kinds of plants in all parts of the country.

Chapter 16

Weeds and Weed Killers

WEEDS belong in a discussion of soils for several reasons. For one, modern chemical weed controls introduce problems of toxic residues, which may produce either short- or long-term injury to desirable plants as well as weeds. For another, deep-rooted weeds such as bindweed, Canada thistle and nut grass often make a soil unusable for gardening until they can be exterminated. Third, the amazing longevity of certain weed seeds in soils is a factor in gardening.

Longevity of weed seeds is a serious problem and one which often determines how a certain soil should be treated for lawn or garden purposes. It often becomes critical when a home owner, following "curbstone advice" from neighbors, insists upon buying a load of "good black dirt" to start his new lawn, bringing in someone else's accumulated weed seeds to further complicate matters.

My own most striking experience with seed persistence was with crabgrass. In laying a new water line to my home in 1955, plumbers uncovered an old carriage drive which must have been laid down either in 1868 when the house was built, or in 1900 when it was remodeled. Underneath the old bricks was rich black prairie loam. I dug this out and spread it over my vegetable plot. This was done in early spring, before any crabgrass plant could have contaminated the soil with fresh seed. Nevertheless, that spring, a heavy crop of crabgrass sprang up from this long-buried soil. Thus those seeds retained their viability for a minimum of 55 years.

CONTROLS

There is only one 100 per cent control for long-lived buried seed—sterilization of the soil with live steam for several hours. This is feasible only in greenhouses, where special covers are used on benches to retain heat and pressure at a lethal level. Practical control can be had in home gardens or future lawn areas by the use of one of two chemical materials.

Calcium Cyanamid: Used at a rate of 75 pounds to 1,000 square feet of surface (a heavy dose) this has killed out all weed plants and seeds for me, even on fairly heavy clay soil. Calcium cyanamid, called Garden Cyanamid, is a granular material that at first breaks down into substances poisonous to seeds but later converts into valuable nitrogen and lime. It is a grim coffin-gray in color and even *looks* poisonous to handle, but is perfectly safe if used as directed. The soil to be treated should be plowed or rotary tilled and leveled just before application. After 60 days you can plant seed, but *disturb the soil surface as little as possible,* to avoid bringing up new weed seeds. The 60-day wait is one drawback to this material. Since soil should be warm during treatment, this means you have an unplanted lawn or garden during the major part of the growing period, which some gardeners find too unpleasant a sight to face.

A lawn I treated in this way four years ago came up without a single weed and, except for a few seeds blown in from the outside, has had no weeds since.

Vapam: This is a fumigant, a liquid used in much the same way as garden cyanamid; it works almost as well but for some reason has failed to control purslane, a persistent and annoying weed in my soil. Otherwise, it cleaned out such nasty perennials as Canada thistle and bindweed, as well as all annual weeds. It is somewhat easier to use than calcium cyanamid; soil fumigated with vapam can be reseeded within a week after treatment.

OTHER MATERIALS

A second fumigant, methyl bromide, is not generally practical for amateur use. However, some landscape gardeners are equipped with a device that injects the gas into soil. The area is then covered with a plastic sheet. A day later the cover is removed to air out the fumigated soil. After a day or two, it is ready for seeding.

Chemical control of annual weeds in flower and vegetable plantings is not always easy. Both Sesone or Crag Herbicide 1, and

Alanap are quite effective on selected crops. One difficulty is that they will not discriminate between seedlings of weeds and those of desirable plants.

In a commercial truck garden where a single crop occupies several acres, weed control is possible. Several chemicals can be used that will not hurt a given crop, but will destroy weedy plants. Examples are the use of monuron on asparagus plantings and simazine on sweet corn.

PRE-EMERGENCE CRABGRASS CONTROLS

Perhaps the most spectacular use of chemicals for weed control on home properties is in the pre-emergence materials which will prevent crabgrass in lawns. At present, five materials are fairly well distributed in commerce, each with certain advantages and disadvantages. These are calcium arsenate, chlordane, dacthal, lead arsenate and zytron. Two of them, calcium and lead arsenate, are also controls for three other lawn weeds—knotweed, common chickweed and annual bluegrass *(Poa annua).*

A common impression is that these pre-emergence chemicals kill crabgrass seed before it germinates. This is not the case. If it were, a single application would eradicate this weed for years, since there would be no viable seeds left to produce plants. Actually all of these chemicals work by killing seed immediately after it sprouts and as the seed coat splits. Calcium and lead arsenate kill by "waiting" until the germinating seed has exhausted its extremely small store of phosphorus and sends out its minute new roots to take up a replacement supply of this element from the soil; the arsenic substitutes for phosphorus and kills the tiny plant. Chlordane works by poisoning the root runner as it starts to make growth, checking any further development of the plant.

Solutions of all these chemicals can be applied to dormant crab-grass seed but if the chemical is washed off before the seed coat splits, a normal seedling will develop.

SIGNS OF GERMINATION

These chemicals work by building up a toxic layer an inch or so deep on the surface of the lawn. To work effectively all must be in place before crabgrass seed germination begins. Calendar dates for germination are notoriously unreliable because of the variation between seasons. *Instead, use natural signs* which appear when a certain number of degree hours have accumulated, not when a certain date appears on your calendar pad.

Here are some natural signs that announce the imminent appearance of the first crabgrass seedlings: *Magnolia steUata* dropping its petals; *Magnolia soulangeana* in flower; first buds open on French hybrid lilacs, first blooms on Darwin tulips, and apple blossoms showing trace of pink.

LIST OF THE BEST

The principal pre-emergence chemicals and their function characteristics are as follows:

Calcium Arsenate: In many ways this is the most practical of all pre-emergence crabgrass controls. It gives between 95 and 100 per cent control. Granular types are not as satisfactory as those adsorbed on vermiculite to form a heavy powder that clings to soil and does not blow away. Granular forms also tend to wash away from point of application in heavy rains. The granular forms are less desirable, too, because birds may pick up the bright particles. The vermiculite-type clings and is not easily picked up, and it does not adhere to the feet of pets and children.

Precautions to observe: For two weeks after applying calcium arsenate, do not fertilize and do not reseed bare spots. After two weeks, if a fertilizer is used, apply one that is low in phosphorus, or use a straight nitrogen product for that season. Most lawns have adequate reserves of phosphorus and potash, so skipping one application won't hurt.

The question is often asked, "Are these weed killers dangerous to birds?" Calcium arsenate adsorbed on vermiculite contains 4 per cent soluble arsenic which kills earthworms in their burrows so they do not come to the surface. Other forms (and lead arsenate) may kill the worms after they have surfaced. Birds that eat these poisoned worms can be killed.

Plus advantages: Calcium arsenate kills many harmful soil insects such as white grubs, Japanese beetle larvae, and others. Do *not* expect control of third-year June bugs which are about to emerge, but all feeding forms will be dead by midsummer. This chemical will also kill common chickweed if applied in fall. Incidentally, even if applied in fall it is equally effective in spring on crabgrass. Calcium arsenate checks knotweed so that it is easier to kill with ordinary lawn weed killers. It checks Poa annua so that it does not form seed.

Residual effects: One application has been known to give three-year control of crabgrass. However, a booster shot of about one-third the strength recommended on the package for initial treatment, applied in either spring or fall of the second and third year, will insure 100 per cent control. But do not continue using either of these materials for more than three years; depend on a thickened turf to control crabgrass after that period.

Lead Arsenate: I have used this chemical off and on since 1936. I have gone back to it despite its defects because other chemicals did not always give the desired control. But I feel that today it has been superseded by calcium arsenate, which is cheaper, more effective and less likely to damage turf. The one place where lead arsenate does have value is in control of knotweed, but for this purpose it must be applied during a February thaw. Knotweed germinates at that time, and if lead arsenate is present, the knotweed seeds will be killed.

One drawback to products containing lead arsenate is their dustiness—free white arsenic may fly in the air. Be sure the wind is blowing away from you when applying. A dust mask is a reasonable precaution. All forms of lead arsenate I have tested offer some hazard to birds, since worms tend to come to the surface to die.

Chlordane: This product is worth considering if soil insects are a problem; it has no superior as a treatment for such pests. Its control of crabgrass has been somewhat less than satisfactory. I am sorry to see this, as I was the first to publicize it as a crabgrass control and helped launch a commercial chlordane crabgrass killer about nine years ago. This was based on research work in Colorado and California, where chlordane gave outstanding control of crabgrass, equal to that of calcium arsenate in less arid areas.

For some reason—which might be intensity of sunlight, pH of the soil, soil moisture or some unknown factor—the farther east we come, the less effective chlordane seems to be against crabgrass.

Chlordane may perform beautifully in one lawn, but fail in another. It can be expected to give about 25 per cent control as a minimum, but this will still mean hundreds of thousands of crabgrass plants in a home lawn. Instances where chlordane has given good results are frequent enough so that it has been kept alive as a crabgrass control, but it is far too erratic in action for an out-and-out recommendation except in the West. For Colorado and California and perhaps as far east as parts of Kansas, I would rate it tops.

A major advantage is that desirable lawn grass seed can be sown four or five days after chlordane is applied.

Dacthal: This relatively new pre-emergence chemical (introduced for the first time in 1960) has proved an excellent control for crabgrass. It has two drawbacks. The first is its residual threat, the most severe residual effect on seeds of permanent grasses of any of the five materials mentioned. It is *not* harmful to established turf, but *it will not allow reseeding of bare spots the same season it is used.* In spite of this strong one-season residual, it does not carry over winter and must be reapplied the following spring. Dacthal seems to be best suited for use on a lawn where permanent grasses are thick but occasional crabgrass plants are annoying. Its big advantage is cost—perhaps the cheapest material sold for this purpose.

Zytron: This material was test-marketed during 1960 and gave excellent control of crabgrass in eight limited areas in the Middle West. Recalling my experience with chlordane and its strong regional adaptation, I would not want to go on record as recommending zytron outside the Middle West. Package recommendations suggest a 10-week wait before reseeding with permanent grasses.

The full residual period of zytron has not yet been determined, but it is being recommended largely as a one-season control.

COMBINING PRE- AND POST-EMERGENCE

Because pre-emergence application dates are so rigidly fixed by the appearance of the first crabgrass seedlings, I have been running extensive tests on the advantages of combining pre- and post-emergence techniques. At first I thought a late spring application of a pre-emergent (even after the first seedlings appeared) would eliminate enough crabgrass to be worth while since it would control everything appearing later. Unfortunately, while this did give control of later seedlings, the spring crop was so enormous (about 75 per cent of the seed usually sprouts at that time) that the lawn looked as though 100 per cent of the current year's crop had survived. My next move was to apply both post- and pre-emergence controls. When these materials went on together, however, injury to permanent grasses was often severe. Spacing the two treatments three weeks apart saved the turf but control from post-emergence treatment was not always satisfactory because of low temperatures which often occur in spring.

Solution of this problem came with the introduction of a chemical called Super Sodar, an improvement on the older dry Sodar powder. It is not properly a Sodar product, since it does not contain *disodium* methyl arsonate but is a mixture of ammonium methyl arsonate and dioctyl methyl arsonate. It is, however, a very effective post-emergence crabgrass control and will work at lower temperatures than most chemicals in this class.

The program, then, is to apply calcium arsenate on vermiculite as early as possible in spring, even if crabgrass has germinated, and to follow this three weeks later with a spray of Liquid or Super Sodar (on some containers this may be listed as AMA).

TOXIC RESIDUES IN SOILS

I have gone to some lengths to describe the action of these weed killers because this has a bearing on the residues the chemicals leave in soils. We can dismiss chlordane's four- to five-day residual effect (on plants) as unimportant. This must, however, be distinguished from its four- to five-year residual effect on soil insects.

Both calcium and lead arsenate toxicity (carelessly caused by excessively heavy doses) can be overcome with a heavy application of superphosphate (about 75 pounds to 1,000 square feet) or with ferric sulfate (iron sulfate, but be sure you use the ferric form, not ferrous). The rate on ferric sulfate is quite high—10 pounds to 100 square feet—but for spot treatment might be feasible. This heavy a dose of iron sulfate will, of course, kill grasses and other plants so the remedy may be as bad as the disease.

One of the worst weed killers, in so far as residual effect goes, is sodium arsenite. This is an old material: there has been some kind of a sodium arsenite weed killer on the market since 1888. It will sterilize soil so that nothing can grow there for two to three years. This is excellent on drives and walks, where I use it regularly. I spray a thin line along a fence where no mower or tillage tool will go. It keeps weeds from growing there for years. Fortunately, it does not wash once it has become fixed on soil, so I can spray within a few inches of desirable plants.

Ferric sulfate, 10 pounds to 100 square feet, is the remedy for sodium arsenite toxicity. Next, put on gypsum to neutralize any remaining sodium particles.

TWO MAJOR HERBICIDES

I recall how, when I was working with 2,4,5-T in 1943 and 1944, I would say to myself, "But what is this doing to soil bacteria?" I couldn't see how this stuff could kill plants and not be equally toxic to bacteria. Yet nothing seemed to happen to the bacteria or other microorganisms, even after repeated spraying. Later, we found that this was not a toxic chemical that destroyed directly, but affected growth abnormally. Since they attacked the cambium layer of broad-leaved plants, bacteria (having no cambium layer) were safe.

Later an even more astonishing fact came to light. When we tried to trace 2,4-D and 2,4,5-T to see what happened to them in soils, they had disappeared. Bacteria had actually used them as food—had "eaten" them completely. With each successive application, the period these chemicals could remain in soil uneaten became shorter and shorter. This meant that the population of chemical-eating bacteria was increasing and using up this strange food faster and faster. In one series of tests where bacteria of this type were transferred from one flask to another, always with plenty of 2,4-D to eat, they used up over 98 per cent of the chemical after 70 transfers in four days.

Many of the chlorinated phenoxy compounds cause a similar response. Since their breakdown in soils is linked to bacteria, temperature plays a vital part in their disappearance. For example, if either 2,4-D or 2,4,5-T are applied just before soil freezes in winter, bacteria are inactive and do not consume them. As a result, the chemicals persist in the soil and if they come in contact with certain deep-rooted, hard-to-kill weeds, will destroy them through prolonged exposure to 2,4-D effects.

The one drawback to this method is that no plants susceptible to 2,4-D can be seeded early in spring in a soil treated in late fall with 2,4-D because it will still be there. *After two weeks during which soil temperatures are in the 60s, it will be safe to sow seeds of most vegetables and flowers.*

Substituted Urea Compounds. Under such names as Neburon, Diuron, Monuron and Fenuron, these are being used to control weeds under a wide range of conditions. They differ considerably in such qualities as solubility, persistence in soils, species of crops on which they are safe, weeds they kill and in other respects. They are considerably more residual than 2,4-D, so when a weed killer is wanted for a period of weeks, selection of a proper formulation of a substituted urea compound is perhaps the answer. These chemicals are digested and destroyed by soil bacteria but at a much slower rate than 2,4-D.

Aminotriazole: This specialized weed killer is perhaps the best we have for control of nut-grass, poison ivy and Canada thistle. It deserves special mention because of the furor it raised in the fall of 1959 during the cranberry fiasco. Aminotriazole seems to be considerably more persistent in soils than any 2,4-D type of material or certain forms of the substituted ureas. In laboratory tests, only about one-fifth of it disappeared 35 days after exposure to soil organisms.

I feel that because of this persistence, aminotriazole (in the hands of the amateur) should be confined to use around ornamentals where such hard-to-kill weeds as nut-grass, poison ivy and Canada thistle must be destroyed.

Additional Materials: New weed control chemicals are emerging from the laboratory; it is impossible to keep up with them. In addition, there are hundreds of materials already in commerce. There is, however, one fundamental and universal principle which must be followed in handling such materials, namely, read and adhere to the package directions.

If you only knew how many hours of work and testing went into the preparation of directions to protect you from personal injury and to protect your plants, you might appreciate how important it is to put on your bifocals and read all the print on the package. Above all, if a manufacturer thinks it is important to tell you his product has a residual period of 10 weeks, *believe him.* He isn't anxious to limit his sales; hence any restriction of this kind is put on the package for *your* protection.

WASHING OUT SOLUBLE WEED KILLERS

Many of the less-persistent weed killers are fairly soluble and will move downward in soil if subjected to heavy watering. Most of the 2,4-D products, for example, can be removed from surface soil by applying two inches of water. To know when you have applied two inches of water, set coffee cans at intervals under the sprinkler and when the can with the least water in it contains two inches, turn off the hose. Reseeding can be done immediately.

This washing (as well as rainfall), by the way, does not spoil the effect of the chemical on weeds you want to kill, provided the water does not go on for at least eight hours after application of a triethanolamine salt, a sodium salt or an amine form of 2,4-D or 2,4,5-T. If ester forms of the chemicals are used, only one hour need elapse before it is safe to wash the soil, since ester types penetrate the plant tissues within that time.

CHAPTER DIGEST

Weed control is closely connected to soil care. The finest Gardener's Loam is not worth much if blighted by weeds. With the help of a great and ever-increasing selection of chemicals, the home owner can bar many kinds of undesirable plants from his lawn and garden. It can be done in three "stages": sterilizing the soil, killing germinating seed, and destroying mature weed plants. But weed-killing chemicals, too, present potential hazards from the build-up of toxic residues in the soil. In any event, the faithful observance of instructions on the package will assure maximum protection as well as value to the user, to the plantings being treated, and to the soil itself.

Appendix

Item 1

SOIL PREFERENCES OF PLANTS (pH READINGS)

Since practically no scientific work has been done to establish standards and limits of plant tolerances for acid or alkaline soils, most of the figures on pH range are based on observations by many authorities. The ranges presented here are not hard and fast readings which must be followed to the exact fraction given. (Remember that the pH scale of soil solutions runs from 1.0 [acid] to 14.0 [alkaline], with 7.0 neutral.)

The ability to survive under wide variation of soil is shared by many plants, yet a few are quite exacting in their requirements. When difficulty is experienced in holding a soil to a certain range, the addition of more organic matter will often override the harmful effects of too high or too low a pH.

Many of these figures might be questioned by those who have grown specific plants under other conditions. For example, while 5.5 to 6.9 is given as the proper range for roses, I have seen them grown at readings as high as 8.0 and as low as 4.8. However, when the gardener is striving for healthy plants with generous bloom, he will in general have fewer problems to overcome if he keeps his soil in the range suggested.

Since the principal use of this list will be to determine what plants can be grown under existing conditions, it has been arranged by soil reaction readings, so that all the subjects that can be grown together can be seen at a glance. Those who wish to study the subject more intensely are referred to "Soil Reaction Preferences of Plants," by C. H. Spurway, Special Bulletin 306 of the Michigan State Agricultural Experiment Station, East Lansing, Michigan. This lists thousands of plants, including weeds, trees, shrubs, groundcovers, annuals and perennials as well as farm crops and fruits.

p	Range	Type	Species & Genera
4.	to 5.0	SHRUBS	Andromeda, *Cornus canadensis,* Heaths
0			(Ledum and Leiophyllum), Pieris, Po-
4.	to 5.5	SHRUBS	tentilla, *Magnolia glauca,* Vaccinium
0			Ilex
4.	to 6.5	VEGETABLE	Dock *(Rumex acetosa)* Arctostaphylos,
4.	to 5.5	SHRUBS	Blue Hydrangea, Rhododendron Rhode
5			Island Bent Scabiosa
4.	to 6.0	GRASS	Azalea, Gardenia Irish
5			
4.	to 7.5	ANNUAL	Potato, Sweet Potato
5.	to 5.5	SHRUBS	Redtop
5.	to 6.0	VEGETABLES GRASS SHRUBS	*Acer pennsylvanicum* & A. *sfncatum,* Aronia, Benzoin, Betula, Callicarpa, Camellia, Ceanothus, Chamaedaphne, Chionanthus, Comptonia, Corylopsis, Cytisus, Fothergilla, Indigofera, Kalmia, Leucothoe, Lyonia, *Magnolia grandiflora,* M. *soulangeana* & M. *stellata,* Myrica, Nandina, Photinia, Skimmia, Stephanandra, Styrax, Vaccinium (in high organic soils) *Aconitum papellus,* Androsace Parsley Apple, Oriental crabapples
		FLOWERS	Enkianthus
5.0 to 6.9		VEGETABLE FRUIT SHRUB FLOWERS	*Anemone globosa,* A. *halleri* & A. *vernalis, Pulsatilla vernalis* Bellingham hybrids and L. *bolanderi, canadensis, catesbaei, elegans, formo-sanum, grayi, japonicum, kellogt, phtl-adelphicum*
5.5 to 6.3		LILIES	Carrot, Celery, Chicory, Corn, Cucumber, Dandelion, Eggplant, Endive, Onion, Parsnip, Pepper, Pumpkin, Rhubarb, Squash, Turnip, Watermelon
5.5 to 6.9		VEGETABLES	

pH Range	Type	Species & Genera
	SHRUBS	Roses
	FLOWERS	Amaryllis, Aster (perennial), Begonia, Calendula, Lantana, Pansy, *Phlox drummondi,* Nasturtium, Portulaca, *Salvia splendens*
5.5 to 7.5	FLOWERS	Chrysanthemum, Marigold (Tagetes)
	VEGETABLES	Cauliflower, Collards, Tomato
	GRASSES	*Poa pratensis*
6.0 to 6.9	VEGETABLES	Beans (snap, lima, pole & soy), Broccoli, Celery, Chives, Garden Cress, Horseradish, Lettuce, Mangel, Muskmelon, Onion, Radish
	GRASSES	Agrostis (all Bents except Rhode Island), *Poa trivialis,* Bermuda
	SHRUBS	Amelanchier, *Amygdalus communis,* Aralia, *Cornus florida,* Corylus, Exo-chorda, Genista, Hamamelis, Pink Hydrangea, Itea, Prunus (cherries & apricots), Symplocos
	FLOWERS	*Acanthus mollis,* Astilbe, Calceolaria, China Aster, Cineraria, Clarkia, Coleus, Fuchsia, Gloxinia, Gladiolus, Helianthemum, Heuchera, Iberis, *Iris germanica, LUium aura turn,* L. *bakerianum,* L. *philippinense,* Narcissus, Poinsettia, Primula, Saintpaulia, Schizanthus, Tulips
6.0 to 7.5	VEGETABLES	Asparagus, Beets, Brussels Sprouts, Cabbage, Chinese Cabbage, Kale, Kohlrabi, Mustard, Peas, Salsify, Spinach, Swiss Chard
	GRASSES	Orchard grass, Perennial & Italian Rye-grasses, (and crabgrass)
	LILIES	L. *Amabile,* Backhouse hybrids, L. *Browni,* L. *bulbiferum,* L. *caUosum,* L. *candidum,* L. *cernuum,* L. *chalcedoni-cum,* L. *concolor,* L. *croceum,* L. *dauri-cum,* L. *davidi,* L. *hansoni,* L. *henryi,* L. *longifiorutn,* L. *mart agon,* L. *mona-*

pH Range	Type	Species & Genera
		delphicum, L. *pardalinum,* L. *farryi,* L. *regale,* L. *sargentiae,* L. *speciosum,* L. *tenuijolium,* L. *testaceum,* L. *umbellatum*
	SHRUBS	Ailanthus, *Daphne cneorum,* Forsythia, Fraxinus, Ribes (cultivated currants), Viburnum
	FLOWERS	Ageratum, Alyssum, Anagallis, Anchusa, Antirrhinum, Aquilegia, Aubrietia, Dianthus (carnation), Celosia, Centaurea, Cynoglossum, Dahlia, Delphinium (annual & perennial), *Dicentra spectabilis,* Digitalis, Dimorphotheca, Gaillardia, Geum, Godetia, Ipomaea, Gypsophila, Lobelia, Lupinus, *Mirabilis jalapa,* Nigella, Papaver, Petunia, *Salvia jarinacea, Vinca rosea* Garlic, Leek,
6.0 to 8.0	VEGETABLES SHRUBS	Watercress Abelia, Acacia, Acer (except A. *penn-sylvanicum* & A. *spicatum),* Aesculus, Alnus, Amorpha, Berberis, Buddleia, Buxus, Calycanthus, Cephalanthus, Chaenomeles (Cydonia), Citrus, Cornus (except C. *florida* & C. *canadensis),* Cotoneaster, Deutzia, Dirca, Eleagnus, Euonymus, Hibiscus, Hypericum, Ker-ria, Kolkwitzia, Laburnum, Ligustrum, Lonicera, Mahonia, Malus, Philadel-phus, Prunus (ornamental varieties), Pyracantha, Rhamnus, Rhodotypos, Rhus, *Ribes alpinum,* Robinia, Sambu-cus, Sorbaria, Spirea, Symphoricarpos, Syringa, Tamarix, Weigela Adonis, Althaea,
	FLOWERS	Amaranthus, *Anemone alpina* & A. *cylindrica,* Crocus, Gilia, Heliotrope, Mesembryanthemum, My-osotis, Paeonia, Phlox (perennial)

P Range	Type	Species & Genera
6. to 7.5	FLOWER	Lupinus (western varieties)
	MUSHROOM	Meadow mushroom (cultivated)
7. to 8.0	SHRUBS	Baccharis, *Daphne mezereum*

Two flowers are so tolerant that they will grow in any pH from 5.0 to 8.0. These are the Cosmos and Mignonette.

Item 2

READING FOLIAGE

An examination of plant foliage

often reveals whether the soil contains all food elements needed for good growth, and whether the plant is absorbing these elements properly. Plant scientists do this with leaf tests, actually checking concentration of various elements in the leaf itself.

Although not quite as accurate, leaf color tells a great deal about the way roots are taking up food elements from soil. This is usually a better check than a soil test which only reveals what is in the soil and not whether the food elements move out of the soil and into the plant.

DEFICIENCIES AFFECTING UPPER OR YOUNGER LEAVES

Calcium: Terminal buds remain smaller than normal or are shriveled and dead; tips and edges of leaves brown and curled; balance of leaf not affected or only slightly yellowed.

Boron: Terminal buds similar to calcium deficiency. Leaf stems are brittle and base of leaf yellowed. Tips not affected until last.

Iron: Blade of leaf is pale or yellow while larger veins remain green. Smaller veins turn yellow with blade of leaf. Later, edges of leaves turn brown.

Sulfur: Entire leaf turns yellow, with veins brighter than blade. No further change throughout the season.

Manganese: All veins remain green while blade turns yellow. Later, blotches of brown appear over entire leaf (not only on edges as in the case of iron deficiency).

Nitrogen: Veins turn a reddish color while blade turns light green or yellow.