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FERTILIZERS AND COVERCROPS FOR CALIFORNIA DECIDUOUS ORCHARDS

E. L. PROEBSTING¹

IN CALIFORNIA, the use of commercial fertilizers as an aid in producing full crops of deciduous fruits and nuts has increased from a small amount at the beginning of this century to about 20,000 tons in 1941. Many growers are following a satisfactory procedure. Others, however, have not yet determined the best practices for their orchards. This circular will suggest a foundation for sound fertilization programs, on the basis of the experimental data available and of the growers' experience in various fruit-raising districts.

In planning any such program, one should keep in mind a few general considerations. The mineral elements necessary for the normal nutrition of the tree are absorbed through root surfaces close to the growing tips of the roots. New roots may grow through a particular bit of soil, then die, and be replaced by new roots once or several times each year. During growth, they absorb water and minerals. A mature tree will have developed a system of permanent roots extending throughout the available soil mass, together with innumerable temporary, small, feeder roots.

Whether or not the roots can absorb enough for the normal needs of the tree will depend on soil fertility, depth, texture, moisture, and temperature; drainage and aeration; the species of tree and the rootstock on which it is grown. Trees may secure as much from a good soil only 4 feet deep as from a poor one of twice that depth. On shallow soil, they will rarely perform satisfactorily even if the soil is good, the irrigation well handled, and fertilizer supplied. Root branching may be unsatisfactory in either very coarse or very heavy soils, resulting in inefficient extraction of nutrients from a given volume of soil.

Roots will not grow in dry soil nor—with most species—saturated soil.

¹ Associate Professor of Pomology and Associate Pomologist in the Experiment Station.

Such conditions reduce the active root surface and probably the efficiency per unit of root surface, thus limiting the nutrient absorption. As has been demonstrated, this absorption depends on soil temperature. The critical temperatures vary with species. For trees, the lower limit is probably near 45° F; the maximum rate of activity near 70° F. Above 90° F the activity is slight, and at slightly higher temperatures death of the roots will occur. In order to grow and function, tree roots need oxygen. Saturated or tight soil through which the air can move only slowly will not provide good environment. Different species of trees have different habits of root growth, some branching profusely, some very sparsely under the same conditions. Likewise, different roots have different abilities to extract nutrients from a given soil. It has been found, for example, that the same variety of apple growing on two selections of rootstocks on a potassium-deficient soil will show deficiency symptoms on one of these stocks and not on the other.

In order that any added fertilizers may be absorbed, they must be brought into areas where the roots can come in contact with them. The depth to which they must penetrate will depend on conditions in the orchard. If there is sod, for example, the roots may grow to within an inch of the surface, whereas in some clean-cultivated orchards, where the soil temperature may be high, there may be but few roots in the top foot. In the latter case the fertilizer must be a kind that will penetrate with rain or irrigation water, or else must be placed in the root zone mechanically in order to be absorbed by the tree.

Not all fertilizers, even though soluble, will move downward with water. Most soils have the ability to fix some of the common fertilizers. Potassium (potash, or K) is fixed—that is, taken out of solution and held—by most California soils. Even on sandy soils whose fixing power is less than that of the heavy soils, large surface applications are necessary for penetration into the root zone. Phosphate (P) also may be retained in large amounts by the surface soil. Some of the nitrogenous fertilizers, including all ammonia compounds, are fixed temporarily, but in the soil are changed by bacteria to nitrate, a form in which the nitrogen is free to move.

The ready movement of nitrate is important, not only for transfer to the root zone, but also for washing through the root zone and being lost in the drainage water. The loss of nutrients may be serious in light soils subjected to heavy rainfall or excessive irrigation.

Loss may also occur in soil that remains saturated for a considerable period, a condition suitable for the destruction of nitrogen compounds. This so-called denitrification process results in release of gaseous nitrogen to the atmosphere.

DETERMINING NEED OF FERTILIZATION

Many California orchards are on soils capable of supplying all the nutrients needed for maximum production. Under these conditions, additions of any sort are not profitable. Some soils had a lower initial reserve of one or more nutrients, or were more depleted of their initial supply and now require replenishment. For maximum production the grower must know the status of his orchard.

Of about a dozen mineral elements known to be necessary for plant growth, three—namely nitrogen, phosphorus, and potassium—are known as commercial fertilizers. They are used by plants in large amounts and have proved deficient for some plants in many places throughout the world. The other elements fall into two groups. Of these, one contains calcium, magnesium, and sulfur, which are likewise used in large amounts, but are seldom too low for plant growth, though they may be needed as soil amendments;² and the other group contains manganese, iron, boron, zinc, copper, cobalt, and molybdenum, which are necessary in minute amounts and are known as minor or “microelements.”

Several methods of determining fertilizer needs have been suggested, and some progress has been made with them. The oldest is chemical analysis of the soil. As indicated in the introduction, many factors besides the actual supply of nutrients in a soil will affect their absorption by a particular kind of tree. For this reason we cannot classify a soil on this single basis with any reliability. Certain tests, however, made by one experienced in interpreting the data for the species concerned, will be a useful supplement to other information. Complete soil analysis, as practiced by early workers, has little or no value. This type of analysis includes all forms in which an element may be present, and it does not differentiate between “available” and “nonavailable” fractions.

Various laboratory methods of determining the available nutrients have been developed. These methods may show the approximate total supply of an element that a plant can use, but not the rate at which it may be available for a particular crop. If the supply is found to be very large, one may usually assume that there is an adequate amount. If it is exceptionally low, one may infer the need of following up the status for the low material. No field, however, is uniform in composition; and the soil varies in character at different depths. To be of any value, a soil sample must be taken near the roots and must be representative of the area. If the change in soil character over the area is great, samples from each type of soil must be taken.

² The California Agricultural Code calls these materials “agricultural minerals” and classifies manure, peat, straw, and similar substances as “soil amendments.”

In recent years several types of kits for determining the available nutrients in the field have been placed on the market. The correlation between tests with these kits and the response of trees to the fertilizer practice indicated has been poor, although good results with some field crops have been secured. Such tests are not to be relied upon for deciduous fruit trees. No soil test, whether field or laboratory, thus far used has proved satisfactory for either nitrogen or phosphate. Field tests for potassium have not correlated well with performance. The Neubauer test for potassium, although useful, is slow and expensive, and is not reliable in the range close to a slight deficiency.

Another approach has been the analysis of certain tree parts. Both laboratory and field methods have been developed. With these, as with soil analyses, the results must be interpreted only with due regard for factors modifying the composition of the tissue tested. The composition of leaves will change, for example, throughout the season. Thus the nitrogen content of apricot leaves has been found in one orchard to decrease from 3.75 per cent in April to 2.0 per cent in August. The character and rate of change differ for the different elements and will be modified by size of crop, seasonal conditions, and cultural practices such as pruning, as well as by the available nutrients. As these facts indicate, experience with the method and knowledge of the fruit concerned are necessary for intelligent procedure.

Any chemical tests should be supplemented by observations of the trees. Often there are so-called "deficiency" symptoms that reveal the need of some element. These symptoms, although not completely reliable by themselves, are valuable diagnostic aids when taken in conjunction with soil or plant analyses.

DEFICIENCY SYMPTOMS

The symptoms listed below for deficiencies of various elements are useful in suggesting treatments for controlling the condition in a given orchard. They are not, however, a completely reliable guide; and trial of the elements suggested is necessary before large-scale treatment is in order.

Nitrogen.—The first element in importance as a fertilizer for trees is nitrogen. To produce maximum crops, far more trees need additions of this material than need any other. By no means all California orchards, however, are deficient in nitrogen. Many are plentifully supplied from the reserves in the soil. In bearing trees an acute nitrogen shortage is indicated by pale, yellowish-green leaves, smaller than normal; short vegetative shoots, usually of small diameter; profuse bloom, but very heavy drop, resulting in light set and poor crop; small fruit and early

maturity, followed by early leaf fall. These symptoms appear in the peach sooner than in most other species. If nitrogen is supplied to a tree in this condition, the first response will be an improved leaf color and better growth. Fruit production may or may not be affected the first season. If the per cent set is increased, the yield may be better, and the size improved. The accelerated growth and the larger leaf area will provide a larger and better-nourished fruiting area, which permits the setting of more and stronger fruit buds. This development, in turn, should enhance production the second season. Sometimes this cycle is repeated with annual increases for four or five years.

Potassium.—Deficiency of potassium may result in leaf scorch and dieback, sometimes with burning and shriveling of the fruit. Leaf scorch has been observed in several fruit species. Though usually marginal, it may involve most of the leaf blade. The prune seems particularly susceptible, severe damage occurring under conditions where most other species are not affected. Early loss of leaves and dying back of the tips, followed by new growth from the last live bud, tend to give a zigzag growth, short and brushy. In few cases have trees responded to potassium in the absence of deficiency symptoms.

Phosphate.—Phosphate-deficiency symptoms are less clearly defined in fruit trees. They have been seen almost exclusively in pot culture. Under these artificial restrictions the condition developed is one of stunted growth and dark-green or somewhat bronzed leaves, which may be thickened. Trees grow and produce well on a phosphate-deficient soil in which most annuals fail to make normal development. In a soil having the lowest phosphate-supplying power of any investigated in California, the common species of fruit trees failed to respond to phosphate, although annuals increased five to twenty times their unfertilized checks.

Calcium.—Calcium deficiency, again obtained by pot-culture methods, is shown by a yellowing, or chlorosis, of the leaves. The growing tips may die. Root growth may be markedly reduced, some small roots dying and others developing a short, bulbous growth. No cases have been noted in California orchards. The use of calcium in the form of gypsum or lime as a soil amendment has proved beneficial on certain soils of the state.

Magnesium.—Magnesium deficiency has been reported in widely scattered places over the world, but not, so far, in California. The basal leaves of affected trees develop brownish blotches and drop off. The tips may continue growth while more leaves drop, a few leaves remaining at the ends of bare shoots. Fruit-bud production may be greatly reduced.

Sulfur.—The lack of sulfur seems to cause decreased growth, but few noticeable deficiency symptoms. Although sulfur deficiency has been

found in certain California soils for other crops, none has been reported for fruit trees. Sulfur has, however, been extensively used as a corrective for alkali soils.

Manganese.—Manganese deficiency has been found in several species (notably walnuts) in Ventura, Santa Barbara, and San Luis Obispo counties. The symptoms are interveinal chlorosis in mild cases, death of the interveinal areas in severe cases, with many leaves falling prematurely. Some trees may be practically defoliated by late summer. Milder cases on peaches and apricots, and probably on other species, occur in the interior valleys.

Iron.—Iron deficiency or so-called "lime-induced chlorosis" is common on highly calcareous soils. An important area along the southern end of San Francisco Bay has been known for many years, and other areas have been noted over the state. The lack of iron causes yellowing of leaves, in some cases complete loss of green color. The soils on which trees develop these characteristics are not usually low in iron, but the excess lime renders the iron unavailable.

Boron.—Although boron deficiency is well known in many fruit-growing sections of this country and others, it seems to occur in few of our orchards, except some olives in Butte County foothills. Other species have not yet shown response there. Boron-deficient olives show death of terminal buds, scorch of leaf tips, and little or no fruit set. Deformed fruit known as "monkey-face" may be associated with boron deficiency. The apple seems much more seriously affected by lack of this element than the stone fruits. Nonbearing apple trees develop more or less chlorotic and wrinkled leaves. Bearing trees show dead corky areas (formerly called "drought spot") in the flesh of the fruit. The twigs may die back. In California there is much more injury from an excess of this element than from any lack of it.

Zinc.—A trouble long known as "little-leaf," "rosette," or "corral sickness" has been identified as lack of zinc. ("Corral sickness" has also been used to designate copper deficiency.) Extensive areas in the San Joaquin and Sacramento valleys and smaller spots elsewhere in the state have been found. The most common symptom is a tuft of small, often deformed, yellowish leaves at the ends of shoots. Symptoms vary somewhat with the species. Fruit abnormalities are common, and crops are usually very small.

Copper.—Copper deficiency is rare, but has been found associated with zinc deficiency in some corral spots and old Indian camps, as well as in small areas of pear and apple orchards in the central coast district. Symptoms resemble those of zinc deficiency, but leaf scorch may also occur.

Cobalt and Molybdenum.—Cobalt and molybdenum, though essential for plant growth, are needed only in minute amounts. On the basis of present information, deficiencies seem highly improbable.

PLOT TRIALS IN THE ORCHARD

The ultimate answer to the question of whether or not a tree needs fertilizer must come from the tree. If the analyses and the observations of tree condition point to the need of a particular element, that element should be tried, on a limited scale. If the trial shows a profitable response, a suitable practice can be developed. In laying out such a test, the grower should always expect to find some natural differences between plots, even if there is no differential treatment. Before drawing conclusions, therefore, he should ascertain whether real differences exist. In any comparison he should include enough trees to counterbalance individual tree variation. Detailed records are rarely necessary, though the better the records the more certain the conclusion. For such a trial the number of boxes of fruit per tree is usually an accurate enough index. Some measure, however, is necessary: observation alone may not adequately evaluate real differences ranging up to 20 per cent. Plots of at least ten trees should be used, chosen carefully to represent the average of the block. Before deciding on such a test the grower should be sure the layout will answer his particular question. He may wish to know whether *any* fertilizer will pay, or what element is needed, or how much of a needed material should be used. Without a proper comparison between plots, the effort may be wasted.

FERTILIZATION PRACTICE

Having diagnosed the deficiency in an orchard, one must consider questions regarding the commercial use of the indicated element.

Application of Nitrogen.—For the first element, nitrogen, the most common problems concern source, amount, and time of application. Under normal conditions a wide choice of sources may be made, and the most used forms were ammonium sulfate, calcium nitrate, ammonium phosphate, sodium nitrate, anhydrous ammonia, urea, and calcium cyanamid. This list, though incomplete, includes the bulk of the tonnage. Important organic sources, besides manure and covercrops, were normally fish meal, blood, tankage, and seed meals. Under war conditions many of these sources have been cut off. Of the inorganic sources, only sodium nitrate and limited amounts of ammonium sulfate, anhydrous ammonia, ammonium nitrate, and ammonium phosphate are available. Demands for organic nitrogenous materials for feeds have greatly reduced the supplies of these substances available for fertilizers and have

also increased the prices. There is little point in discussing materials that cannot be obtained. All these materials, however, appear substantially equivalent when equal amounts of nitrogen are used and when the requirements of the particular substance are met.

Sodium nitrate contains about 16 per cent nitrogen. It is completely soluble in water and will penetrate the soil readily with rain or irrigation. Being in the form in which most trees usually absorb nitrogen, it is immediately available. Evidence of increased nitrogen in the leaves may be found within a few days after nitrate has been moved into the root zone by irrigation. The nitrate may be lost below the root zone if excessive rainfall or irrigation follows the application, especially on shallow or light-textured soils. Since root activity is reduced during the winter, at the time when leaching is most likely to occur, this material is best applied shortly before resumption of activity in the spring. It is then available for the tree at the time of fruit setting and during the first flush of vegetative growth. Fruit buds for the succeeding year are initiated within a few weeks after blooming, and nitrogen supplies are necessary for this process as well. Where fertilization has not been practiced and the nitrogen status of the trees is low, the application of nitrate at this period is important. After the tree has had its nitrogen reserves built up by an adequate program, the time of application seems unimportant, provided loss by leaching is avoided.

Ammonium sulfate, which contains about 21.0 per cent nitrogen, is used in much the same way as sodium nitrate. It will not, however, penetrate most soils into the root zone without alteration. It is fixed in the surface soil, where nitrifying bacteria convert it into nitrate; and in that form it is leached into the root zone and absorbed by the roots. The time necessary for converting ammonia to nitrate varies with such factors as temperature, moisture, aeration, and the supply of nitrifying bacteria. In most soils these processes must go on for at least a month before a substantial proportion of the added material can be available. Whereas peaches blossoming in March might well need nitrate the last of February, they should receive ammonia compounds by late January. Some ammonium nitrate, which contains about 35 per cent nitrogen, is available. This material combines the properties of the two forms mentioned above. It leaves no residue. It supplies half of its nitrogen as immediately available nitrate, and half as more slowly available ammonia. It can be easily fitted into the orchard program.

Anhydrous ammonia, which was completely diverted to munitions for much of the 1942 season, is again available. This material contains about 82 per cent nitrogen. It is handled as a liquefied gas under pressure in steel containers and is applied by releasing the gas at a controlled rate

into the irrigation water or by a special appliance into the surface mulch. A distribution problem exists in furrow irrigation where the head is small and the run long. Under these conditions, most of the nitrogen is absorbed at the upper end of the run. With suitable runs and heads, or with square checks or contour basins with adequate rates of flow, excellent distribution is obtained. The ammonia behaves in the soil in the manner described above under the head of ammonium sulfate. Trials with peaches and prunes have given responses to ammonia equivalent to those obtained from the same amount of nitrogen as ammonium sulfate.

Some growers habitually split their nitrogen applications. They apply about half the normal amount in winter. After the fruit has set, they make a second application. A heavy-bearing tree requires a larger supply of nitrogen to produce the crop and to set good buds for the succeeding crop than a light-bearing tree. The second application is regulated in accordance with the crop. If the crop has been destroyed by frost or pests, the second application is omitted. This practice demands more labor, but may save material. During the war emergency, when both men and nitrogen are scarce, the situation should guide the practice.

The rate of application must be based on tree condition and response. Trees that bear normal crops and which at the same time make vigorous vegetative growth probably require little or no treatment. Those making weak growth because of low nitrogen may need, on an average, 60 to 100 pounds of actual nitrogen per acre—equivalent to 300 to 500 pounds of ammonium sulfate or 360 to 600 pounds of sodium nitrate per acre. Higher rates of application are rarely profitable. The amounts indicated above are suggested for those species with a high nitrogen requirement, such as peaches and almonds. Under the same growing conditions, other stone fruits require less nitrogen for best results. Apples and pears likewise have considerably lower nitrogen needs than peaches.

Excessive nitrogen use is not common. In certain cases, however, fruit quality has been impaired and maturity delayed by heavy applications. Moderate excess leads to a few days' delay in maturity, with some fruit in the lower and interior parts of the tree failing to attain satisfactory color. Further excess may give softer fruit of poorer color and flavor over the whole tree.

In many orchards it should be possible to obtain an unusual spread in time of maturity by fertilizing part of the area more heavily than the rest. If maturity is delayed on the more heavily fertilized portion, smaller picking crews may be able to handle the fruit.

The rate of application should be coördinated with other orchard

practices. Trees pruned severely may need less nitrogen than if they were lightly pruned. The covercrop program will greatly modify the need, as will be indicated below. The irrigation practice should be considered, especially on light soils.

The same species or variety of fruit may respond differently in different climates. Apricots, for example, require less nitrogen in the cool coastal areas than in the warmer interior valleys.

Application of Phosphate.—As was indicated above, phosphate has not been needed by trees in those California soils where tests have been made. In a few cases, however, this material can nevertheless be used with profit. These cases involve the indirect benefit secured from good covercrops that require phosphate applications for satisfactory growth on certain soils. If a covercrop is needed, but will not grow without additional phosphate, this material should be supplied. Superphosphate is the standard source. The supplies of this form are not yet restricted, except by transportation needs; but the treble superphosphate and ammonium phosphate may be curtailed. The latter material, containing both nitrogen and phosphorus, is a convenient carrier where both are needed.

Application of Potassium.—In striking contrast to the situation in World War I, there is no shortage of potassium now. Local transportation difficulties may require shifting from potassium sulfate to chloride or manure salts or the reverse; but the total supply is ample. The question, then, is whether or not application is profitable. As pointed out above, there are a few areas in California where potash deficiency has been demonstrated for certain species. Occasionally prunes in the upper Sacramento Valley have shown reduced leaf scorch and dieback and better fruit where rather large amounts of potash have been brought in contact with the roots. The same species has shown response in local areas in the foothills of the Santa Clara Valley. On the soils where prunes have shown potassium deficiency in the Sacramento Valley, almonds and peaches have flourished and produced large crops without any signs of deficiency. In a soil where deficiency symptoms are produced on a particular species, the grower must determine, for each orchard, whether additions of potassium will be profitable. In any trial, for commercial use, the potash must be applied where the roots can absorb it. Most soils will retain far more potassium near the surface than can be economically supplied. For test plots it has proved satisfactory to make, with a crowbar, holes 12 to 18 inches deep at intervals about the tree, and to place in each hole a handful of the material, so that the total amount applied is 500 pounds or more per acre. For larger areas one should use a fertilizer drill that will deliver the material at a depth

of 6 or more inches. Care must be taken not to drill too close to the trees, for large roots may be damaged in that way.

Minor Elements.—Manganese deficiency on most species can be corrected by spraying with a mixture of 1 per cent manganous sulfate, 1 per cent lime, and a spreader (8 pounds manganous sulfate, 8 pounds lime per 100 gallons). Spraying should be done in late spring or early summer. Correction of symptoms should follow in a few weeks. Annual sprays are likely to prove necessary. Manganous sulfate can be added to the soil in holes or trenches, but more material is required. Since the chemical is fixed by most soils, broadcasting is not satisfactory. An experimental method of injecting dilute solutions into holes bored in the trunk or main branches of the tree has given good results, but may admit destructive fungi.

The use of zinc to correct "little-leaf" is widespread. The method must be adapted to the species concerned. Treatments have been made by driving pieces of zinc into the trunk, by applying in holes bored in the trunk, by sprays, and by applying directly to the soil. The last method requires large quantities of zinc sulfate, and the rate of transmission is too slow for rapid recovery. Fixation of the zinc by the soil is an important factor, making it necessary to apply the material in holes or a trench.

The objection to the boring of holes—namely, that rot may develop—applies to zinc as well as to the use of manganese or other minor elements. Thus far, however, it is the only satisfactory method for the walnut. A treatment with dry zinc sulfate in 000 gelatine capsules, placed in holes about 4 inches apart around the trunk, will correct the symptoms for three years or more.

Metallic zinc points, or pieces of galvanized iron, can be used on most species with correction of the trouble for a long period of years. In putting in the pieces one must beware of girdling the trunk or branch: an area around each piece will be killed; and if the areas coalesce, girdling will result. Staggered or spiral placing of points will avoid this difficulty. Pieces should be driven in at about the rate of four to six per inch of circumference. The results are better if branches rather than the trunk are treated.

For stone fruits the most satisfactory method of application is spraying. For severe cases, zinc sulfate sprayed during the dormant season at the rate of 50 pounds per hundred gallons of water is recommended. For cases of moderate severity, half that strength will be sufficient; and for mild cases, as little as 10 pounds per hundred gallons. Summer sprays must be much more dilute, not more than 6 pounds per hundred gallons, and must contain hydrated lime or soda ash at the rate of 3

pounds, to prevent burning. A more satisfactory summer spray is zinc oxide with a spreader, although fruit thus sprayed will be injured.

Copper deficiency is not commonly found where trees are sprayed with bordeaux mixture for the control of disease. Where this material is not used, dry copper sulfate may be added in capsules, as with zinc. Because of the higher toxicity of this material, greater care is necessary. The copper must be kept away from the bark, cambium, and younger sapwood.

The growing of alfalfa in orchards having either zinc or copper deficiency has proved beneficial: mild cases have been entirely corrected, and severe ones greatly improved. Just how the alfalfa functions is not understood. Whether or not the practice is feasible must be decided for each orchard. It is not suitable for such crops as prunes or almonds, where it hampers harvesting operations. Other cultural practices may require modification if alfalfa sod is maintained.

COVERCROPS FOR ORCHARDS

The use of covercrops is intimately concerned with the response of trees to fertilizers. Any crop grown between the trees and turned under can be considered a covercrop, even if it is a weed that volunteers. Whether such a crop will be beneficial or harmful depends on various local factors. In such a system, certain definite objectives are usually sought. The first is the addition of organic matter, not only as a source of nitrogen that will be released over a long period in the soil, but also as a major factor in maintaining good tilth, or soil structure. With continuous cultivation, organic matter tends to disappear. It can be added either by bringing it in from other sources, such as manure or bean straw, or by growing it in place and working it into the soil. Manure or other suitable material is not often cheap enough to warrant the use of adequate amounts. In many orchards the growing of covercrops has tended to replace manuring.

Actual field data regarding the effect of covercrops on soil structure are scanty. Only lately have precise methods of measurement been developed. Much laboratory work has been done to show the effects of adding covercrop material under controlled conditions. The rate of decomposition of different materials under varying moisture and temperature has been studied, together with the effect of these processes on the formation of granules of soil. Certain factors important in the orchard are difficult to study in the laboratory—for example, the formation of root channels through plow sole, or the cracking of certain soils. Since information on many of these points is still not complete, present opinions may be changed later. It seems certain that in many soils there is

better water penetration after a few years of covercrops. The reason may be either that these crops prevent the formation (on wetting) of a tight, nearly impervious layer on the surface of the mulch, as in certain southern California soils; or that they form root channels through the plow sole below the mulch, as sometimes observed in the interior valleys. At Davis, for example, this latter effect was so great that the water from a 6-inch irrigation disappeared from the surface of a covercropped basin in less than 24 hours, whereas across a levee, in an adjacent clean-cultivated check, the time required was a week. More economical use of water and a better supply to the roots will result under these conditions. The use of covercrops is not, however, a substitute for careful soil handling. Cultivation when the soil is too wet will puddle many soils so badly that years of good care may be required to repair the damage. Good soil structure can be developed, moreover, and maintained without covercrops if sufficient care is exercised to avoid compaction. Whenever such care is impossible because the soil is too wet, the use of covercrops may be of great benefit.

One should distinguish between the improved water relations resulting from better penetration, and those from increased water-holding capacity of the soil. Under cool, humid conditions the soil organic matter can be increased by annual covercrops, and with it the total nitrogen and the water-holding capacity of the soil. Under hot, semiarid conditions, this is not the case: the rate of destruction of organic matter is so great that there is little if any net accumulation. At Davis fifteen years of annual covercrops of three types—winter legume, winter nonlegume, and summer legume—have failed to change the moisture-holding capacity of the soil measurably. This factor, therefore, can probably be ignored in California orchards.

Much the same situation exists with regard to total nitrogen as with moisture-holding capacity. Leguminous covercrops with proper inoculation of nitrogen-fixing bacteria have given increases of total nitrogen in cool humid sections; but neither summer nor winter legumes have done so at Davis. There may have been, and probably was, some fixation of nitrogen; but either it has been used so that it does not appear in analyses, or its magnitude is too small to be detected. In sandy soils, where heavy rains might leach nitrate below the root zone, absorption of this material by the covercrop, with later release as the crop rots after being turned under, may save important amounts for use by the trees.

When organic material is incorporated into the soil, most of it is decomposed by soil bacteria and fungi. These organisms, like other plants, need mineral nutrients for their growth and functioning. In the first part of the decomposition period, some of the plant nutrients are usually

decreased in concentration because of absorption by these organisms. The extent of this depletion depends on the supply of the material in the soil (especially nitrate), the condition of the covercrop or other organic material turned under, the moisture supply, and the temperature. Of these factors the most important, usually, is the character of the organic material. If it has a high nitrogen content, as in a succulent covercrop that is not mature, decomposition is rapid. The organisms can secure most of the nitrogen they need from the material itself, and need less from the soil. Because the process is rapid, nitrates are released sooner than with a material lower in nitrogen. Strawy material, high in carbohydrates and low in nitrogen, may cause a depressed nitrate level for months after being turned under.

Obviously, any tendency toward nitrate deficiency in a soil will be much increased by the incorporation of large amounts of low-nitrogen organic matter. Additional amounts of fertilizer will then be needed to supply both the soil organisms and the tree. Covercrops, furthermore, absorb nitrate while growing, and during that period may compete seriously with the tree. One should therefore attempt to correlate the timing of the growth of the covercrop with the fertilizer program and with the needs of the trees.

Covercrops may play an important role on slopes that are subject to erosion. Not only do they increase the rate of penetration of water, and thus reduce the runoff, but their roots tend to hold the soil in place and to reduce the amount of washing by the part that does flow away. The type of crop to be used for erosion control must be one that quickly establishes a root system throughout the surface soil, unless a permanent sod is established. Crops to fit this need have been tried in most districts, and information about their local use can be obtained from the farm advisor of the county concerned.

For convenience, annual covercrops may be divided into four groups: winter legumes, summer legumes, winter nonlegumes, and summer nonlegumes. In the first group the most widely grown are *Melilotus indica* (bitter clover or annual yellow sweetclover), the vetches, and bur clover. Horse beans, fenugreek, lupine, and field peas have been successful in more limited areas. The following crops have had some use as summer legumes: cowpeas; velvet, mung, tepary, and mat beans; soybeans; sesbania; and Hubam clover. Mustards (common, black, and Trieste) and cereals (rye, oats, and barley), together with volunteer weeds, have been the most widely used nonleguminous winter covers. Orchard grass, Sudan grass, and summer-growing weeds have proved satisfactory where summer nonlegumes are desired.

Besides these crops, an increasing number of growers are using per-

manent sod. This system eliminates the cost of cultivation. It is the most effective check on erosion. When the soil is wet it permits orchard operations that are not feasible under clean cultivation. On the other hand, this method requires more water, increased use of nitrogen (even with a leguminous sod), and more rigorous efforts in pest control. It is not suitable for species whose fruit is harvested from the ground—for example, prunes, almonds, walnuts, or figs. Alfalfa has been widely and successfully used. Perennial rye grass has proved satisfactory; and in some areas, volunteer weeds provide throughout the year a succession of plants which, though containing few perennials, serve adequately.

Despite the advantages to be obtained from covercrops, there are orchard areas where they can be used only with danger. Nonirrigated orchards in regions of low rainfall need all the moisture available to take them through the season. The use of any considerable portion of the supply by covercrops may result in failure to mature the fruit and, during very dry years, in severe damage to the trees. Any covercrops used in such areas must be turned under early enough so that the late winter rains will make good the water used by them in the early winter. Under these conditions large tonnages of covercrops cannot be expected, and conditions may prevent the grower from turning the crop under in time to prevent some moisture depletion. The increase in rate of penetration of moisture and the decreased loss by runoff may compensate for the water used, after the practice has been carried on long enough to be effective. Since covercropping must be practiced for several years before water penetration can be noticeably improved, this is still a hazardous program in nonirrigated areas. Furthermore, the growers of stone fruit have found a higher incidence of brown rot in orchards having covercrops at blossoming time.

Now that nitrogen is hard to secure, orchard operations should be so planned that the minimum amount consistent with full production will be used. As is evident from the facts given above, savings can be made by reducing rates of application in heavily fertilized orchards for the duration of the war; by making applications under favorable conditions so that the least possible loss occurs; and by following such cultural practices as covercropping, pruning, and irrigation in a manner designed to minimize the need for this strategic material.