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Fertilization of Ornamental Trees, Shrubs, and Evergreens

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FERTILIZATION OF ORNAMENTAL TREES, SHRUBS, AND EVERGREENS

L. C. CHADWICK

INTRODUCTION

Organic and mineral nutrients have been applied to ornamental plants since early historic times. Lawson in 1618 suggested fertilizing trees with liquid manure in June and July or replacing the surface over the roots with new soil. Austin, writing in 1657, was among the first to suggest fertilizing trees by puncturing the soil with an iron bar. Even tree injection was mentioned by Magnol as early as 1709.

Some present practices follow closely those suggested in the earliest records of history; others, including the distribution of fertilizers in the soil by means of compressed air and water, are modern methods.

It is not surprising that advancements have been made. A better knowledge of the movement of nutritive elements in the soil, coupled with a more thorough understanding of root distribution and the requirements of roots for growth and functional behavior, is responsible for the adoption of the air, water, and air-water methods of application.

METHODS OF FERTILIZER APPLICATION

Fertilizer applications can be classified as soil applications or plant applications. The first of these methods is by far the most important commercially.

SOIL APPLICATIONS

Soil applications are made by surface feeding, trenching, and placing fertilizer in holes.

SURFACE FEEDING

Surface feeding was one of the first methods employed and still is useful under some conditions, especially for the partial feeding of shallow-rooted plants, such as most shrubs and evergreens, and trees with low-hanging branches under which the soil can be worked. Spading in a heavy application of manure reinforced with commercial fertilizers may be useful in increasing the organic matter as well as improving the general structure of the soil.

There are at least two serious objections to the surface method of feeding trees. Since most shade trees are growing under lawn conditions, it is impossible to work the soil beneath them, and applications must be made to the surface and watered in. Even then, injury to the grass is apt to result if heavy applications are made. Wyman (15) showed, however, that as high as 50 pounds of ammonium sulfate to 1,000 square feet could be applied to the lawn without injury to the grass if the applications were made before growth started in the spring. Up to 15 or 20 pounds per 1,000 square feet were applied without injury after growth started. These tests were conducted on heavy clay soils. Such applications to other soil types might react differently. Another weakness of surface application is that some mineral ingredients are very slow in penetrating the soil to depths corresponding to the majority of feeding roots. Phosphorus moves very slowly in the soil and is usually held in the surface inch or two for a period of a year or more. Phosphorus fertilizers applied to the surface and not worked into the soil will, therefore, seldom reach the feeding roots of deep-rooted plants where they can be utilized.

Although the surface method of fertilization does not have much to commend it in feeding lawn trees, it is one of the best and most feasible methods of feeding shrubs and evergreens.

TRENCHING

Trenching is at best an unsightly operation, and rarely do conditions exist where it can be practiced as a general tree maintenance operation. It is a method of stimulating a more fibrous root growth previous to transplanting. Severing the roots by the trench, which is refilled with good soil high in organic matter, aids the development of new fibrous roots. It is quite possible that many of these roots in the fill are destroyed at the time of moving. New roots are also formed within the soil ball, some distance back from the cut ends, following root-pruning. These roots are not destroyed during the moving process and are important to the rapid recovery of the plant.

APPLICATION IN OR THROUGH HOLES

Feeding shade trees by means of applications put into relatively large holes made with a posthole digger is justifiable under certain soil conditions. Where soils are extremely hard, heavy, or of otherwise poor structural condition, more can be accomplished in improving them for satisfactory root growth by adding humus than in any other way. Large holes provide a means of adding this organic matter. As much as a tenth to a sixth of the soil might be replaced at a time. Such replacement with good soil would unquestionably be of considerable benefit and if practiced through successive years, would soon renovate the whole area.

The punch-bar method of feeding has been practiced for a long time and is more universally used today than any other. It has the advantage over surface applications that the fertilizer is down in the portion of soil occupied by the roots. If the holes are placed reasonably close together, a relatively uniform distribution is secured. Some of the questions which might be asked regarding this method of feeding are: Over how large an area should the holes be distributed? How many holes should be made for a tree of a given diameter? How deep should the holes be?

Diagrams submitted with trade literature often indicate that the holes should be staggered around a circle underneath the outer spread of the branches. The theory behind this practice is the assumption that the majority of the feeding roots are located beneath the drip of the branches. The work of Bushey (1), Gourley and Bechenbaugh (4), Pletcher (6), Weaver and Kramer (14), and Yeager (16), to mention only a few, has shown this assumption to be fallacious.

Bushey (1), working with American elms, found that the roots extended in a horizontal radius approximately equal to the height of the tree. Moline elms had a greater proportion of their root systems within a much smaller radius from the base of the tree than did American elms, and Moline elms growing in cultivated fields had a deeper root system than American elms growing in a natural woodlot.

Gourley and Bechenbaugh (4) found fewer roots directly under the drip than within or without this area.

Weaver and Kramer (14) found that the roots of *Quercus macrocarpa* had two to four times the radial spread of the branches.

Yeager (16), after examining root spread on many trees and shrubs, stated that roots extended horizontally 0.4 to 2.1 times the height of the tree.

Ohio Agricultural Experiment Station workers have been studying the root distribution of ornamental trees since 1935 and published a preliminary report of the data recorded, together with methods of study followed, in 1937 (2).

During the year 1937-1938, further studies were conducted on the distribution of roots of Moline elms in relation to fertilizer applications. The trees studied were removed from a block of 8-year-old transplanted Moline elms. In 1931, this block of 500 Moline elms (*Ulmus americana* var. moline) had been planted in rows 8 feet by 10 feet in a well-prepared field of silt loam soil. The field had previously been in alfalfa sod. It has a slightly eastern exposure. The portion of the block from which the trees were taken for root study is described as the Brookston profile and is relatively well drained. The A and B soil horizons were mixed and varied in depth. The C horizon was a yellowish silty clay loam, somewhat sticky and poorly drained. Underlying this C layer was a gravelly and rocky clay.

The original block of 500 Moline elms was divided into 4 sections. One section received applications of fertilizer in spring; one in spring and July; one in July and fall; and one in fall. Each section was further divided into 5 plots of 25 trees each. The fertilizers applied to the different plots in each section were a 12-6-4, a 6-6-4, ammonium sulfate, and a mixture of ammonium sulfate and superphosphate. A plot in each section was left untreated as a check. In 1937, Ammo-Phos (11-48-0) was substituted for the mixture of ammonium sulfate and superphosphate. One of the check plots in the original fertilizer test was replaced with a trade-name 8-5-3 fertilizer. Statements received from the companies manufacturing the trade-name fertilizers 12-6-4 and 6-6-4 indicated that the nitrogen in the 12-6-4 was almost entirely inorganic and that about 90 per cent of that in the 6-6-4 was inorganic. The contents of inorganic and organic nitrogen in the 8-5-3 fertilizer were not ascertained. Applications were made so that each plot received the same quantity of nitrogen at each application, and this during the past 3 years of the experiment has been computed on the basis of a half-pound of available nitrogen for each inch in diameter of the trunk of the tree. The fertilizer was broadcast over the entire area beneath the spread of the branches. Cultivation was practiced throughout the growing season.

Where possible, the trees selected for root study were adjoining trees with approximately the same diameter 2 feet above the crown. Two trees were selected from each of the fall-fertilized plots, four from the check plots. The method adopted in removing the trees for root study consisted in laying off the area in 1-foot squares and digging a trench at the outer extremities of the roots. Every root, with its size in millimeters, depth in inches, and length in each foot square, was recorded. Drawings were made, and the roots cut off where they entered the next foot. As each 1-foot strip was removed, the line was moved 1 foot nearer the center of the tree until the center was reached. The area on the other side was recorded exactly the same as the first, but the worker progressed outwardly from the center of the tree, thus utilizing the trench already dug The depth of the roots from the surface of the soil was recorded to the nearest

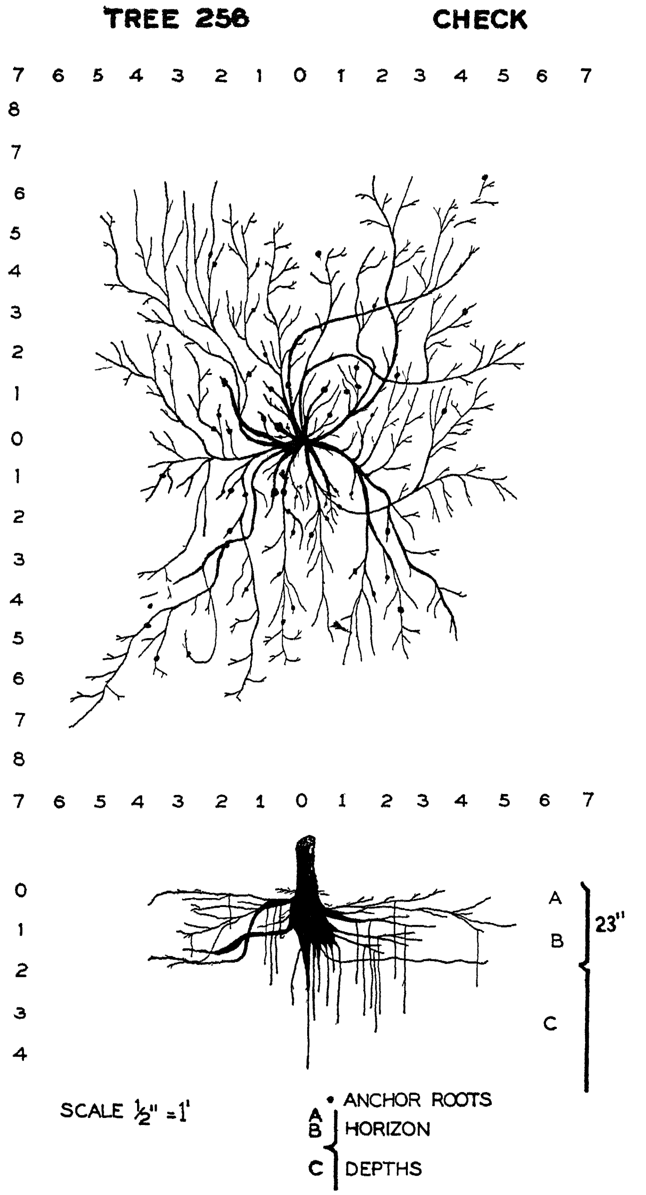

Fig. 1.—Trees taken from the check plots, of which Tree No. 256 is an example, showed the smallest number of roots and comparatively few of these showed fibrous root development.

inch, and the diameter of each root was measured to the nearest millimeter where it entered the next foot of soil. Roots dropping down vertically from a lateral are called anchor roots. The depth of the anchor roots was measured in inches from the point at which they turned downward to the farthest point of penetration. After each root of appreciable size was measured, its course was plotted on scaled paper. A cross-section view of the roots of the tree was drawn to scale in the field at the time of the removal of the tree. The degree or extent of the fibrousness was noted for each root measured. With the aid of the field drawings and measurements, careful diagrams of the root spread and penetration of the roots were made to scale. These diagrams were later photographed (fig. 1-6). Calculations were made as to the number of measurements taken at each depth, the number of each size of root measured, and the number of roots carrying fibrous roots as measured in each square.

It is impossible to present here all the figures and measurements recorded. Since the two trees studied from each plot were as comparable as possible, the figures given regarding the height of the tree, root spread, and the like, will be for only one of the trees, but the figures for the root measurements will be the average of the two trees from each plot. The figures mentioned in the discussion may not, therefore, agree with the figures in the tables, since the individual tree records may be cited.

In this report, "root counts" are referred to, since it is not possible to speak in actual terms of individual roots because the same lateral root may be several feet long and therefore measured in several different squares. It was ascertained from careful observations that the average lateral branch root would be measured three times in different squares. It will be observed that with each tree studied, a statement appears concerning the root counts bearing fibrous roots. This count should not be interpreted as the actual number of fibrous roots, but as the number of root counts bearing fibrous roots.

The number of anchor roots varied from 23 to 91. Anchor roots did not penetrate into the soil in proportion to their diameter. Regardless of the number of anchor roots to a tree, the average length of all the anchor roots for a single tree ranged between 20.74 inches and 29.44 inches. Generally the deepest anchor roots were found within a 2-foot radius of the crown. Anchor roots penetrated into the closely packed clay layer (C horizon) and in some instances penetrated into the gravelly layer below the C horizon. The number of anchor roots is not consistent with fertilizer treatments.

In analyzing the results on the different plots (table 1) it will be noticed that the trees from the check plots show the least average number of root counts and, therefore, the least number of roots; also, with the exception of the trees fertilized with 12-6-4, the least number of root counts bearing fibrous roots.

Since the trees fertilized with 12-6-4 and with 6-6-4 received the same quantity of nitrogen, not much difference would be expected between them if nitrogen were the only element responsible for growth. There is not much difference in the number of root counts, but the number of root counts bearing fibrous roots is 82 for the 12-6-4 plot, 451 for the 6-6-4 plot (table 1). The trees fertilized with the 6-6-4, however, received twice as much phosphorus as those fertilized with 12-6-4, and the difference in the fibrous character can probably be ascribed to this difference in phosphorus application. Miller (5) reported that applications of phosphorus promote the formation of roots, especially lateral and fibrous roots. This statement might explain the difference

TABLE 1.—Root studies on Moline elms

Tree No.	257	30	51	79	104	137
Fertilizer treatment	Check	12-6-4	6-6-4	Ammonium sulfate (20 per cent)	11-48-0	8-5-3
Diameter	3¼ in.	3¾ in.	3½ in.	3¼ in.	3¾ in.	3¾ in.
Height	12 ft. 9 in.	12 ft. 8 in.	12 ft. 4 in.	13 ft. 7 in.	14 ft. 2 in.	14 ft. 7 in.
Root spread, diameter	12 ft.	16 ft.	12 ft.	12 ft.	14 ft.	15 ft.
Soil tests: pH	5.7	6.2	4.8	5.3	6.0	5.5
Nitrogen	0 p.p.m.	10 to 25 p.p.m.	25 to 50 p.p.m.	25 to 50 p.p.m.	5 to 10 p.p.m.	25 to 50 p.p.m.
Phosphorus	0 to ½ p.p.m.	0 to ½ p.p.m.	½ to 1 p.p.m.	0 to ½ p.p.m.	5 p.p.m.	0 to ½ p.p.m.
Potassium	0 p.p.m.	20 p.p.m.	10 to 20 p.p.m.	0 p.p.m.	0 p.p.m.	0 p.p.m.
Depth to C horizon of soil	25 in.	25 in.	26 in.	27 in.	19 in.	22 in.
Number of root counts	855	950	1,018	1,102	1,439	1,001
Number of anchor roots	50	37	77	26	65	60
Average length	22 in.	23 in.	29 in.	24 in.	22 in.	22 in.
Number of root counts measured carrying fibrous roots	140	82	451	160	228	278

in results between the 12-6-4 and 6-6-4 plots, but it does not explain the difference when 6-6-4 is compared with 11-48-0. The 11-48-0 as applied would supply about four times as much phosphorus as the 6-6-4, but still the 6-6-4 trees had about twice as many root counts bearing fibrous roots. This result might be explained on an optimum phosphorus basis by showing that this particular soil type does not require the heavy application of phosphorus supplied by the 11-48-0 fertilizer. It might also be recalled at this point that the 6-6-4 fertilizer supplied some potassium, whereas the 11-48-0 supplied none.

Although the plot fertilized with ammonium sulfate received no phosphorus, the trees in it had more root counts bearing fibrous roots than did trees fertilized with 12-6-4, but they showed a much smaller number of root counts bearing fibrous roots than did any of the other fertilized trees. The use of ammonium sulfate showed slight indications of toxicity, especially on those roots that were near the surface of the soil. Observations and records compiled, however, make it clear that the differences in the fibrous roots and the location of roots cannot be explained on the basis of toxicity.

With all the trees studied, the majority of the horizontal roots did not enter the C horizon but developed above it. From 96 to 100 per cent of the root counts were in the first 24 inches from the surface of the soil, 79 to 98 per cent in the first 18 inches, 48 to 86 per cent in the first 12 inches, and 17 to 47 per cent in the first 6 inches.

The higher percentages of roots in the first 6 inches were in the plots fertilized with the 6-6-4 and 8-5-3 fertilizers, and the lower percentages were in the 12-6-4 and 11-48-0 plots (table 2). These results would seem to indicate that the 6-6-4 and 8-5-3 fertilizers favored the development of a shallow root

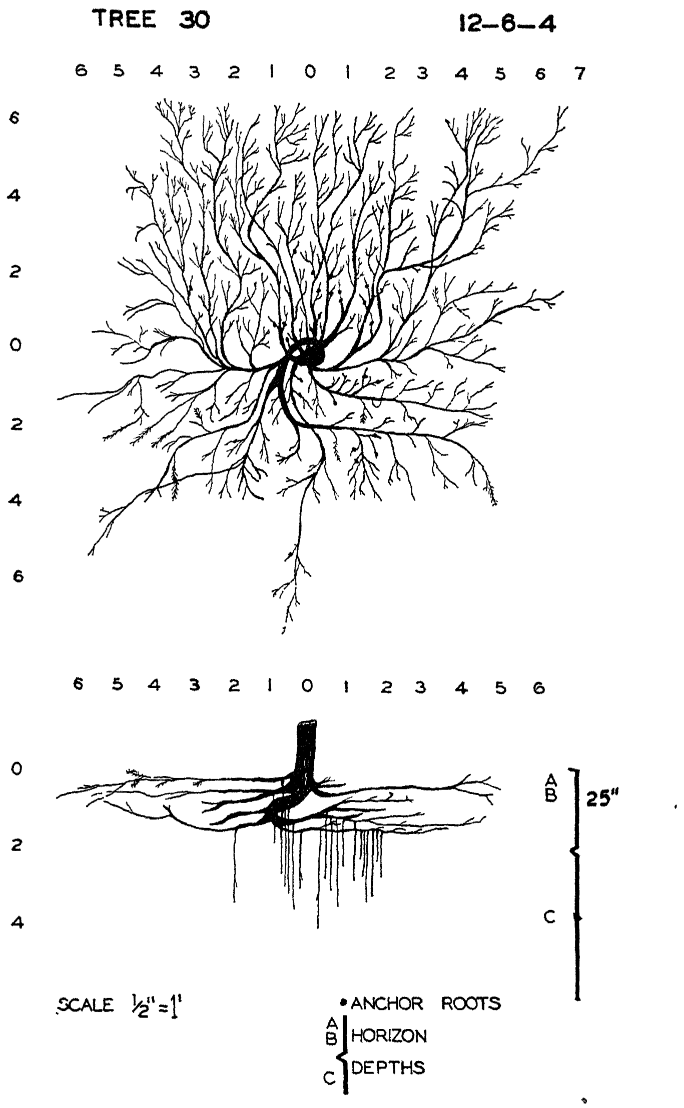

Fig. 2.—Trees taken from the plots fertilized with 12-6-4, of which Tree No. 30 is an example, showed a comparatively deep root system and a relatively wide-spreading root system. Trees from this plot gave the lowest number of root counts of any fertilized trees and the lowest number of roots bearing fibrous roots.

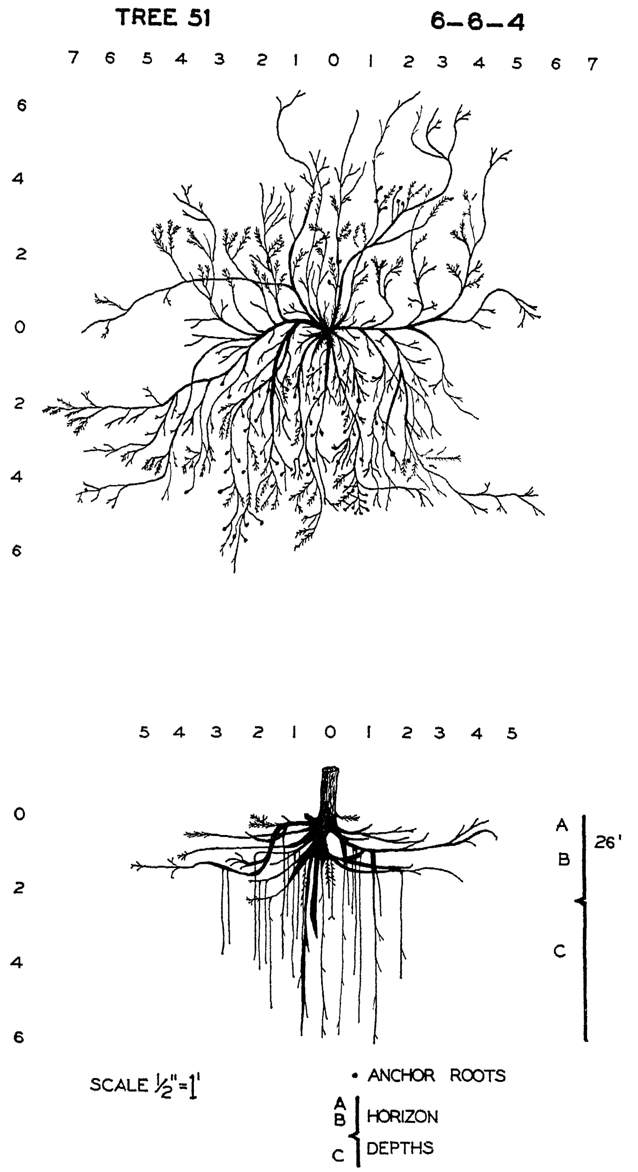

Fig. 3.—Trees taken from the plots fertilized with 6-6-4, of which Tree No. 51 is an example, showed a comparatively shallow root system and an average-spreading root system. Trees from this plot had the largest number of roots bearing fibrous roots.

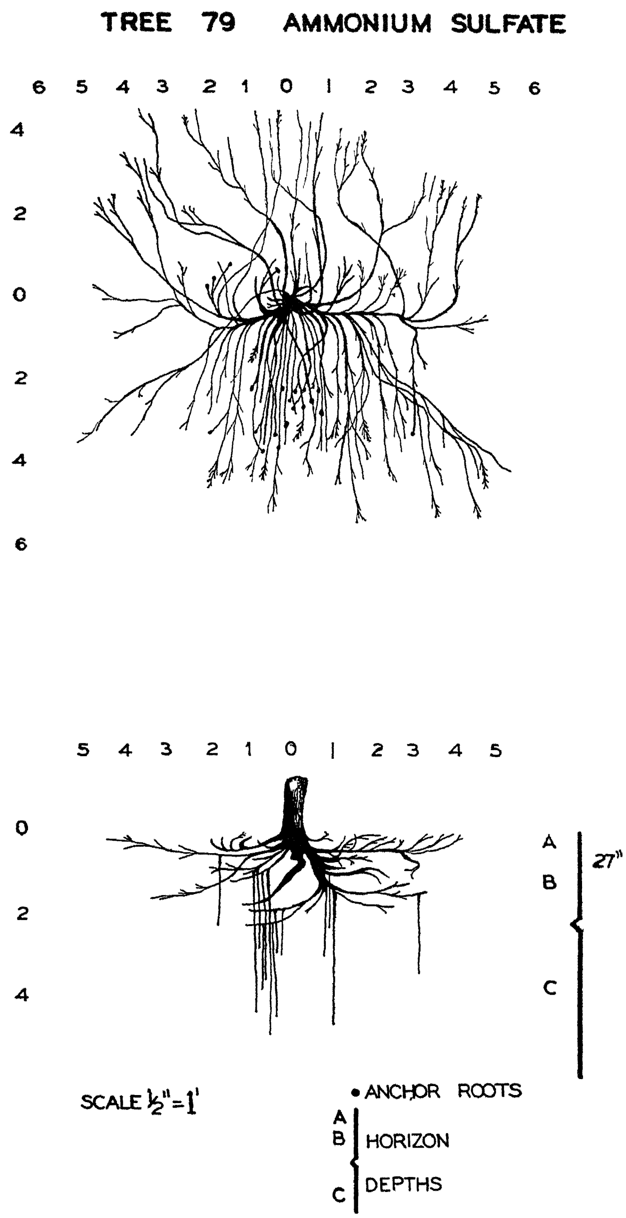

Fig. 4.—Trees taken from the plots fertilized with ammonium sulfate, of which Tree No. 79 is an example, showed a comparatively deep root system but with a high concentration of roots near the trunk of the tree. Trees from this plot gave a high number of root counts but comparatively few carried fibrous roots.

system, whereas the 12-6-4 and 11-48-0 favored the development of a deeper root system. They cannot be explained on the basis of difference in drainage or the depth of the soil C horizon. There was practically no difference in the structure of the A and B soil horizons in the different plots, and table 1 shows that the C horizon was reached at 19 inches for Tree No. 104 (fertilized with 11-48-0) and at 26 inches with Tree No. 51 (fertilized with 6-6-4).

TABLE 2.—Depth and spread of roots of Moline elms

Treatment	Accumulative percentage of all root counts at different vertical levels				Accumulative percentage of root counts 2 mm. or less in diameter at horizontal radial distances from trunk of tree							
	0 to 6 in.	7 to 12 in.	13 to 18 in.	19 to 24 in.	First foot	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot
Check .	28	69	92	99	44.0	64.7	82.6	92.8	98.2	99.9	100	....
12-6-4.....	22	55	84	99	46.2	68.8	81.7	90.6	97.3	99.7	99.9	100
6-6-4.......	40	67	87	98	52.3	77.3	89.4	96.3	99.0	99.4	100	......
Ammonium sulfate	25	68	89	98	66.7	83.6	91.5	96.3	98.5	100	....	... .
11-48-0.....	22	62	86	98	61.1	78.0	89.4	95.2	98.2	99.2	100	....
8-5-3......	40	74	95	100	38.6	64.6	78.5	91.0	97.6	99.0	99.6	100

The difference in amounts of inorganic and organic nitrogen carried by the different fertilizers might be considered an important contributing factor in the depth of roots. Since, however, 90 per cent or more of the nitrogen in both the 12-6-4 and 6-6-4 was inorganic, this factor does not seem to be important in this study. The highly acid soil reaction of the plots fertilized with 6-6-4 does not seem to be the contributing factor to the shallow root system, since the trees fertilized with 8-5-3 also showed shallow roots.

It may be noted again that Miller (5) found that phosphorus promotes a deeper penetration of roots as well as a fibrous root system. The deeper penetration of roots on trees fertilized with the 11-48-0 fertilizer supports this statement.

The subject of root distribution is concerned not only with the depth of the roots from the surface of the soil, but also with the horizontal radial spread from the center of the tree. Table 2 gives the accumulative percentage of root counts 2 millimeters and under in diameter at horizontal radial distances in feet from the center of the tree. This count includes those roots from the surface of the soil to the ultimate depth. These figures were calculated by taking the root counts for two strips 1 foot in width extending perpendicular to each other through the center of the tree to the extremity of the root system.

Table 2 shows that all the root counts 2 millimeters and less lay within a radius of 8 feet for all trees studied. Ninety per cent or better of these root counts were within a 4-foot radius. The figures also indicate that the 11-48-0 fertilizer and the ammonium sulfate tended to bring about a concentration of roots near the trunk of the tree. From the standpoint of the size of the ball required when moving the trees, this would be a favorable condition. It might not prove as advantageous in maintaining satisfactory growth and condition of trees subject to soil moisture deficiencies and heavy winds. The 8-5-3 and 12-6-4 fertilizers seemed to cause a more spreading root system.

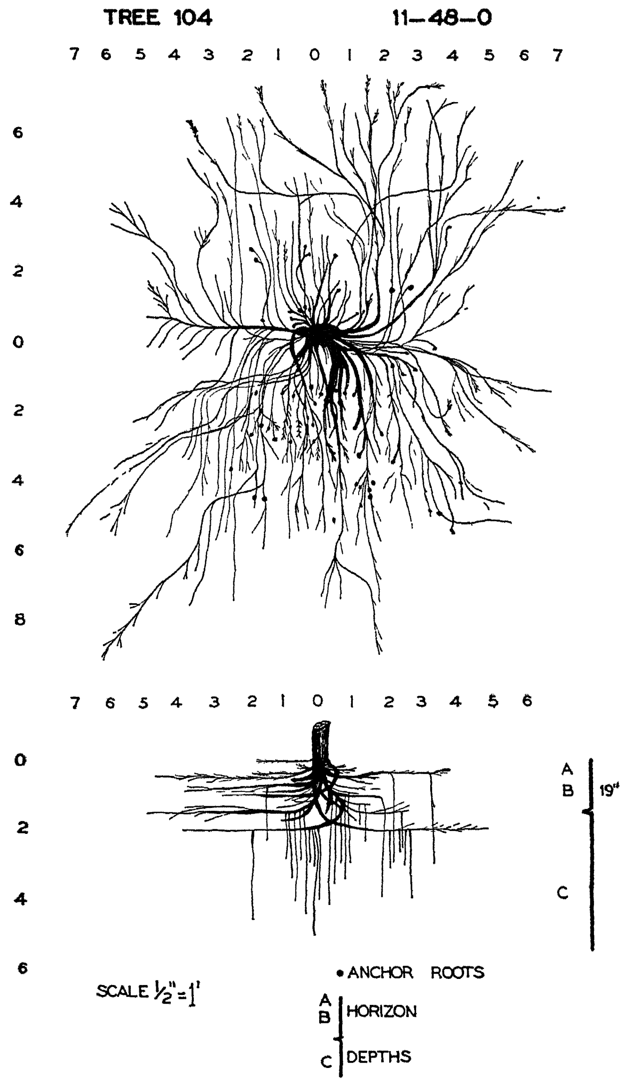

Fig. 5.—Trees taken from the plots fertilized with 11-48-0, of which Tree No. 104 is an example, showed a comparatively deep root system but with a high concentration of roots near the trunk of the tree. Trees from this plot had the largest number of root counts and second largest number of roots bearing fibrous roots.

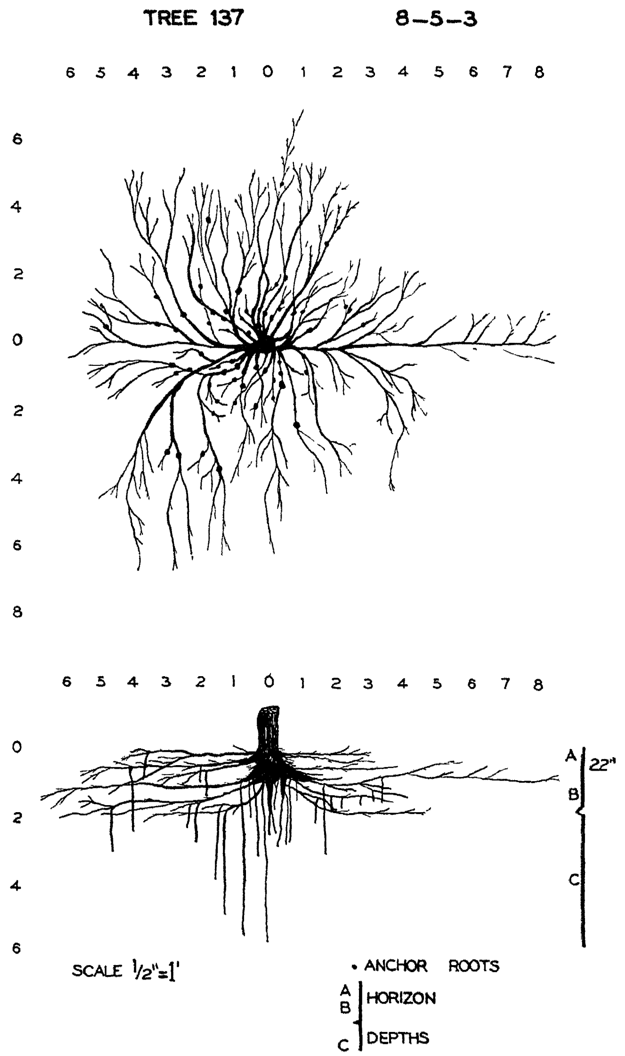

Fig. 6.—Trees taken from the plots fertilized with 8-5-3, of which Tree No. 137 is an example, showed a comparatively shallow root system but a relatively wide-spreading root system. Trees from this plot gave an average number of root counts but a high number of roots bearing fibrous roots.

According to the results of this study, the location of the holes for fertilizing should start within a short distance of the trunk and extend well beyond the spread of the branches. The radius of this area in feet would be approximately one and a half to two times the diameter of the trunk in inches. This area would include approximately 100 per cent of the feeding roots. If the grower wishes to be conservative, he can limit the holes to an area whose radius in feet corresponds to the diameter of the trunk in inches. This more limited area would still include about 90 per cent of the feeding roots. Larger trees and different soil conditions might show different responses. For larger trees, growing in unlimited soil areas, it is probable that the holes should be distributed over the area beneath the branches and extending beyond the spread of the branches a distance equal to half the branch spread.

In feeding a tree, it is suggested that as a general rule, to be modified as conditions necessitate, 15 to 25 holes be made for each inch in diameter of the tree trunk. On this basis, if 5 pounds of tree food were used per inch in diameter of the tree trunk, one-third to one-fifth pound would be added to each hole. This practice should give a relatively uniform distribution.

The necessity of placing the holes close together is based on the fact that there is little movement of fertilizer elements, other than nitrogen, from the holes in which they are placed. Nitrogen is nearly always present in true solution and moves through the soil mass with the soil water. Practically all the other nutrients, such as phosphorus, potassium, calcium, magnesium, and boron, are not readily mobile within the soil but are adsorbed on the surface of the soil particles. In fact, Wander and Gourley (13) have shown that phosphorus moved less than 1 inch from the hole over a period of 3 years. Potash will move 4 to 6 inches during a similar period. These results show that the holes in which fertilizer is placed must be close together and that the plant must have a well-developed root system for maximum utilization of plant nutrients.

The depth of the holes should correspond to the penetration of the majority of the feeder roots, which will vary a great deal with soil type, kind of tree, and perhaps the kind of fertilizer used. Most of the literature on the subject stresses the maximum depth of root penetration without stating where the majority of the feeder roots are located. Figures presented in table 2 indicate that from 84 to 95 per cent of the fibrous roots are within the first 18 inches of soil. As a general statement, a depth of 15 to 18 inches would be ample for the holes. A soil auger is a better implement than the crowbar for making the holes, since its use does not compact the soil about the hole.

The aero-fertil method of tree feeding consists of using a pneumatic drill with a 1¼-inch auger. Holes are bored to the desired depth and frequency, usually 18 to 24 inches deep and 30 to 48 inches apart. The air gun is placed in the hole, the throttle opened, and air emitted to fracture the soil to as much as 10 feet from the point of application. After the soil has been broken, the air gun is removed, the fertilizer placed in the hole, the gun replaced, and air emitted to blow the fertilizer through the fractured soil. Sometimes the holes are drilled deeper and placed in a row to drain surplus water off to a lower level.

Recently, methods of using water to make the holes and distribute the fertilizer have been devised. One such pressure-feeding gun consists of standard galvanized pipe fittings to which a soil rod is attached at one end and a funnel or hopper at the other. Valves regulate the flow of water and fertilizer. The soil rod, made of ¼-inch pipe, is 40 inches long. Hose lines lead to a sprayer, which furnishes the necessary water and pressure. In drilling the hole, the soil rod is placed in contact with the soil, and the stopcock controlling the water supply from the sprayer is slowly opened. The water forced out of the tip of the gun drills the hole. After drilling, the water is turned off, and the lever under the funnel is opened. The fertilizer is poured in, the valve closed, and the water is turned on again to force the fertilizer underground. The ease of operation and effectiveness of such a gun would undoubtedly vary with soil conditions. About 3 gallons of water are used with each charge of fertilizer. Not all feeding is done at times when such quantities of water are necessary or desirable. Undoubtedly, however, there are times when such additional quantities of water would greatly benefit the plant, resulting in greater stimulation of tree growth than would an application of tree food in a dry state.

A number of other types of guns for liquid feeding have been used. Some consist of a soil rod to which a hose from a power sprayer is led. The fertilizers are in solution in the sprayer and are forced through the rod into the soil under pressure. One of the criticisms of this method is the excessive wear and corrosion on the sprayer.

A late innovation in forced-feeding equipment is a combination air and water gun. The holes are drilled with compressed air, as in the aero-fertil method. The gun consists of a tube which extends into the hole, a cylinder into which lead the air and water lines, both controlled by valves, and a hopper into which the fertilizer is placed. After the hole has been drilled, the gun is inserted and the soil fractured; then while the air is holding open the soil fractures, the hopper is opened, and the fertilizer is blown or washed in by opening the air valve or the water valve. Three or four gallons of water to 1 pound of fertilizer are used. Either the air or water or both can be used to distribute the fertilizer. The condition of the soil will govern the forcing agent used.

TREE APPLICATIONS

Direct application of materials to plants may be made by spraying or injection.

APPLICATIONS BY SPRAYING

Spraying as a means of applying nutritional material is confined largely to treatments to overcome certain mineral deficiencies. This method has shown considerable promise as a means of overcoming iron-induced chlorosis of citrus, apple, pin oak, and other fruit and ornamental trees. Frequent applications are necessary, and thus other methods of applying, such as direct injection and soil treatments, are often more reliable and economical.

TREE INJECTION

Collison, Harlan, and Sweeney (3) pointed out in 1932 that the injection method of nutrition was very much in the experimental stage. This condition has not greatly changed. Methods of injection of dry salts, solutions under gravity from feeder bottles suspended above the place of injection, and solutions under pressure have all been tried and found to have certain serious limitations.

Absorption of the nutrient solutions is not uniform, and considerable resistance seems to be built up in the tree against the absorption of some elements. Distribution in the tree is mostly vertical, and a number of injections into the trunk of each tree or into the base of each main limb is necessary. Since it appears that the same hole can be used for only a single injection, the extensive boring over a number of years would seriously weaken the tree. Under some circumstances, boring can be eliminated and the injection made through a small cut branch.

The extent of the injury to the tissues from each salt has not been definitely shown, but probably only small amounts of solution can be used safely. Urea has given some promise as a means of increasing the nitrogen content of the tissues. Doses of 1 gram of the salt to 1 inch in limb circumference caused no injury.

A report by Roach (7) from the East Malling Research Station, Kent, seems to be a little more promising. Cox Orange Pippin apple trees were injected with a complete fertilizer solution containing 0.25 per cent of potassium phosphate plus 0.25 per cent of urea, least toxic of the nitrogenous carriers tried, at rates varying from one-thirtieth to one-sixth pound per tree. Sufficient quantities were absorbed in 24 hours to bring about considerable growth increase, equivalent to that resulting from heavy soil applications. Roach (8, 9, 10, 11) has also recently advocated the use of the injection method as a means of diagnosing mineral deficiencies.

TIME OF FERTILIZER APPLICATIONS

The most favorable time for fertilizer application depends on two factors, temperature and moisture. Although spring has been the general period of applying fertilizers, recent experimental work indicates that with shade trees at least, fall is just as favorable or more favorable. Recently, investigators have pointed out that root activity continues until relatively late in the fall. Rogers (12) showed considerable root activity occurring at 45° F. and maximum growth taking place at 65 to 69° F. Rogers further showed that root growth was considerably reduced early in July and that the slow development continued until fall. This failure of favorable response of root growth during the summer months may be due partially to unfavorable temperature, but more to lack of sufficient moisture.

Since root growth does proceed at least until early winter in most of Ohio, it is presumed that fertilizer materials applied in the fall will be absorbed to a considerable extent and that little will be lost by leaching. Furthermore, if they are applied correctly, there is little possibility of the stimulation of top growth late in the fall that might be injured over winter.

The fall application should not be made until after the fall rains have amply moistened the soil. Tests have shown that about October 1 is a favorable time at Columbus, Ohio. Many times, soil temperature and moisture will be more favorable for rapid growth in the fall than in the spring. In the spring, soils are often too cold and may contain too much water at the time fertilizer should be applied.

To give further evidence on the best time of application, as well as on the kind of fertilizer to apply, tests were started in 1931 on Moline elms. These tests continued on the basis of the original plan until curtailment of funds made it necessary to modify the experiment to some extent during 1938. Plots 7, 8, 9, and 10, which had previously received fertilizer applications both in the fall and in July, received an application only during July. No fertilizer was applied to plots 17, 18, 19, and 20, which had previously received applications of fertilizer during the spring and again during July. Within this section, however, an application of straw 1 foot deep was made to plots 18 and 19. The new setup gave plots to be fertilized in spring (usually April), summer (July), and fall (October). In addition, it gave an opportunity to study the benefits of straw mulch (plots 18 and 19) and the residual effect of previous applications of fertilizer (plots 17 and 20).

Since the roots of the trees in adjoining rows between plots had intermingled, it was considered advisable to eliminate one row between plots. Thus fertilizer was omitted from the first row of each plot, and the measurements for these trees were not included in the compiled results for 1938 and 1939. Many of the trees in these adjoining rows were actually removed for root study.

Table 3 presents data for each plot during 1938 and 1939. Table 4 presents composite data recorded during the years 1933 through 1939 for all fertilizers applied at the different periods. The inconsistency of the data recorded indicate that fertilizer experiments on woody ornamentals out of doors must be of a long-time nature, and this requirement is becoming more and more apparent as the experiment progresses.

TABLE 3.—The response of Moline elms to fertilizer treatments

Plot	Fertilizer applied	Amount applied		Time of application		Average diameter of trunk per plot		Average increase in caliper per plot	
		1938	1939	1938	1939	1938	1939	1938	1939
		Lb.	*Lb.*			*In.*	*In.*	*In.*	*In.*
				Oct.					
1	Control	......	......	......	......	2.95	3.32	0.50	0.38
2	12-6-4	12.5	14.5	4	3	3.41	4.03	.57	.59
3	6-6-4	25.0	29.0	4	3	3.54	3.96	.66	.47
4	Ammonium sulfate (20 per cent)	7.5	8.75	4	3	3.59	4.01	.52	.41
5	Ammo-Phos (11-48-0)	13.5	16.0	4	3	3.88	4.23	.55	.41
				July					
7	12-6-4	12.5	14.5	11	25	3.48	3.93	.40	.46
8	6-6-4	25.0	29.0	11	25	3.49	3.93	.59	.44
9	Ammonium sulfate (20 per cent)	7.5	8.75	11	25	3.28	3.66	.41	.46
10	Ammo-Phos (11-48-0)	13.5	16.0	11	25	3.82	4.29	.56	.50
11	Control	......	......	......	......	3.48	3.92	.44	.37
				Apr.	May				
12	12-6-4	12.5	14.5	15	12	4.14	4.66	.57	.55
13	6-6-4	25.0	29.0	15	12	3.45	3.88	.62	.63
14	Ammonium sulfate (20 per cent)	7.5	8.75	15	12	3.00	3.40	.47	.54
15	Ammo-Phos (11-48-0)	13.5	16.0	15	12	3.48	4.03	.55	.57
17	12-6-4 (1932-1937)	......	......	......	......	3.57	3.99	.49	.56
18	6-6-4 (1932-1937), 12 in. of straw mulch (1938-1939)	......	......	......	......	3.77	4.53	.52	.80
19	Ammonium sulfate (20 per cent) (1932-1937), 12 in. of straw mulch (1938-1939)	......	......	......	......	3.22	3.97	.50	.73
20	Ammo-Phos (11-48-0) (1932-1937)	......	......	......	......	3.04	3.58	.57	.57

Adequate rainfall is necessary for a favorable reaction from fertilizer applications. The rainfall during the different seasons and the topography of the soil will explain many of the seasonal variations.

Data compiled during 1940 give further evidence to support the statement that adequate rainfall is essential to favorable reaction from fertilizer applications. Data recorded in 1940 show fall applications giving 0.43 inch increase in trunk diameter, while spring applications gave 0.48 inch increase. Meteorological records show a deficiency of rainfall during the fall and winter of 1939-1940 of 5.48 inches. In contrast, the excess of rainfall during the spring of 1940 was 4.98 inches.

Differences between the plots are becoming more and more apparent. These differences are most apparent in the plots fertilized with 12-6-4, which are decidedly better than the control plots and those fertilized with ammonium sulfate.

TABLE 4.—Yearly and composite average increase in trunk diameter in inches per section

Section	Plots	1933	1934	1935	1936	1937	1938	1939	1933–1939
Fertilizer applied in fall (Oct.)	2, 3, 4, 5	0.27	0.33	0.76	0.55	0.54	0.58	0.47	0.50
Fertilizer applied in July	7, 8, 9, 10	.27	.24	.80	.56	.59	.49	.47	.49
Fertilizer applied in spring (usually Apr.)	12, 13, 14, 15	.25	.19	.76	.54	.59	.55	.57	.49
Controls	1, 11	.19	.27	.74	.52	.50	.47	.38	.44

Table 4 shows that the differences between the periods of application have not been great but that the relationships have been fairly consistent throughout the course of the experiment. Based on the average increase in trunk diameter and including all fertilizers, the fall application has been equal to or better than the spring application, except in the years 1937 and 1939. Fall applications only showed a greater increase in trunk diameter during 1938 than 1937; however, except for 12-6-4 in the fall plot and 12-6-4 and ammonium sulfate in the spring plots, spring applications only showed a greater increase in trunk diameter during 1939 than 1938. It will also be noted from the figures in table 3 that the 12-6-4 was the only type of fertilizer showing an increase from fall over spring application for 1939. Spring applications led for all other types of fertilizer. The relationship of the fall to the spring applications in 1939 can probably be explained on the basis of the low rainfall during the fall of 1938 and the high rainfall (6.06 inches) during June 1939. This condition would favor the spring-fertilized plots. Such a result also shows that conclusions relative to fertilizer applications to shade trees must be based on composite data over a period of many years to overcome the influence of seasonal variations.

KIND OF FERTILIZER TO APPLY

The kind of fertilizer to apply depends mainly upon two things: the formula and the actual ingredients that go to make up the formula.

The question of favorable formulas has been the subject of considerable debate. Pomologists, after many years of experimentation, feel that nitrogen is likely to become the first limiting factor so far as soil fertility is concerned. This statement will probably apply to woody ornamentals as well as to fruits. Much of the evidence at hand indicates that nitrogen alone will give just as favorable response as a complete fertilizer for a few years, although the complete fertilizer may be more desirable in the end. This end result is probably responsible for the trend toward the use of complete fertilizers rather than nitrogen alone for both fruits and ornamentals.

It is probable that the chief reason why responses of trees to phosphoric fertilizers have not been nearly as striking as responses of cereals and other herbaceous plants to them is the failure of the roots to come in contact with the phosphorus applied. It has already been mentioned that the penetration downward is very slow and that the movement radially in the soil is almost nil. Much of the experimental work reported gives no evidence that phosphorus has been well enough distributed in the soil to warrant expecting much stimulation from it.

TABLE 5.—Yearly and composite average increase in trunk diameter, in inches

Section	Plots	1933	1934	1935	1936	1937	1938	1939	1933-1939
12-6-4	2,7,12	0.26	0.30	0.82	0.59	0.56	0.51	0.53	0.51
6-6-4	3,8,13	.28	.22	.79	.52	.61	.62	.50	.51
Ammonium sulfate (20 per cent)	4,9,14	.23	.19	.66	.51	.57	.47	.47	.44
Ammo-Phos	5,10,15	.30	.26	.77	.58	.54	.54	.50	.50
Controls	1,11	.19	.27	.74	.52	.50	.47	.38	.44
Straw mulch	18,19	......	......	......	......	......	.51	.77	.64*
Fertilized previous to 1938 with 12-6-4 and 11-48-0, no fertilizer during 1938 and 1939	17,20	......	....	......	.....	......	.48	.56	.52*

*Composite average increase for 1938 and 1939 only.

The data recorded in table 5 show that applications of complete fertilizers or Ammo-Phos are most beneficial. In 1937 and 1938, the 6-6-4 fertilizer showed the highest increase in trunk diameter. In 1939, 12-6-4 gave the largest increase when the data of all seasons were combined. 6-6-4 applied in the spring gave the greatest increase of any one block. The 12-6-4 gave the greatest increase when applied in the fall and 6-6-4 and Ammo-Phos when applied in the spring. The composite results given in table 5 show that the average increase in trunk diameter for 1933-1939 was practically the same for the 12-6-4, 6-6-4, and Ammo-Phos. Ammonium sulfate has given the poorest results each year except 1937, when it was second in order. The control plots have varied considerably, but an average of them shows a striking decrease in trunk diameter growth since 1935. This decrease was especially noticeable during 1939.

There was a striking increase in caliper during 1939 on trees mulched with straw. Although the benefits of a mulch have been reported with fruit trees, these results, as well as the possible residual effect of fertilizer in plots 17 and 20, are too meager to be conclusive. No doubt the straw mulch tends to conserve moisture, provide a more uniform moisture content, a cooler and a more uniform soil temperature, and possibly an accumulation of some of the essential mineral elements. No explanation of the slight superiority of plots 17 and 20 over fertilized plots is offered. Some root injury may have resulted from the fertilizer applications, but it had not been apparent from past root studies.

It would seem from the results reported that the formula should contain at least nitrogen and phosphorus. The evidence in support of phosphorus in the formula is supplied by the poor response of the trees to ammonium sulfate alone and by the increased amount of fibrous roots produced when ample quantities of phosphorus were used (table 1). There is no possibility of arriving at a single most desirable formula for all plants under all soil conditions, and such a formula is not necessary. The use of the rapid soil tests will give a basis for the application of fertilizer materials, and often only a single element will be required. Under these conditions, it is uneconomical to use a complete fertilizer. With most shade trees, but to a more limited extent with the smaller plants, it is advisable to use a complete fertilizer.

Although some commercial arborists may undertake the mixing of their own fertilizer, this is not advisable for the small operator or the home gardener. Consequently, it is necessary to select a type of fertilizer from the formulas on the market. Granted that this formula should be high in nitrogen, with smaller amounts of phosphorus and potash, the choice is of such standard grades as 12-6-4, 10-6-4, and 8-5-3. On the basis of present evidence the combined phosphorus and potash in the formula need not be greater than the nitrogen. If the rate of application is based on the amount of available nitrogen, the actual formula, within the limits stated, makes little difference.

Whether the nitrogen source should be organic or inorganic or both has likewise been the subject of considerable discussion, and the question is far from being solved. The particular conditions under which the fertilizer is to be applied should regulate the selection of the actual ingredients. For quick results, ammonium sulfate and nitrate of soda are best. These sources are also cheaper than the organic nitrogen materials. Ammonium sulfate is the cheapest source of nitrogen available at the present time. The organic nitrogen materials, such as cottonseed meal, soybean meal, tankage, and the like, are more slowly available but are more lasting. Phosphorus can be furnished by superphosphate or Ammo-Phos. The latter, although more expensive, is more readily available. Potash is usually furnished by muriate of potash. If one mixture were to be advised, it would be composed of an organic material furnishing 25 to 30 per cent of the nitrogen, Ammo-Phos furnishing a large portion of the phosphorus and much of the inorganic nitrogen, and ammonium sulfate, superphosphate, and muriate of potash furnishing the balance of the mixture. A ton of such a fertilizer might be composed of 1,200 pounds of cottonseed meal or soybean meal, 600 pounds of ammonium sulfate, 150 pounds of Ammo-Phos (11-48-0), and 50 pounds of muriate of potash. No consideration is given in this mixture to the trace elements. Where conditions necessitate larger amounts than are contained as impurities, they can be added.

RATE OF APPLICATION

Applications of fertilizers made to plantings of shrubs and evergreens are usually based on the square foot area of the bed. Recommendations for these applications are given at the end of this bulletin.

The recommendations for applications of fertilizers to shade trees are most often based on the caliper of the tree. Another rule that has been proposed is to add to the height of the tree in feet, the branch spread in feet and the circumference of the trunk 1 foot above the soil in inches. If the object of fertilization is to maintain normal plant growth through a well-conceived program, rather than to force considerable succulent growth, this rule will often give too heavy an application.

A good policy to follow is the application of a certain rate of available nitrogen per inch in diameter of the tree. Experience gained from the tests reported and others shows that for trees below 6 inches in diameter, application of one-fourth pound of available nitrogen, and for trees over 6 inches in diameter, of one-half pound of available nitrogen per each inch in trunk diameter is sufficient. If the tree to be fertilized were 10 inches in diameter, the requirement would be 5 pounds of available nitrogen. If the fertilizer formula carried 10 per cent of available nitrogen, as would a 10-6-4, the amount to add would be arrived at by dividing the 5 pounds by 0.10 (10 per cent), which would equal 50 pounds. The use of other formulas and variable-sized trees would be figured in a similar way. This rate of fertilization is based on an unrestricted root system. A tree which has its roots restricted by curbs, sidewalks, or buildings cannot be fertilized as heavily as a tree growing under lawn conditions with an unrestricted root system. The extensiveness of the root system under different soil conditions will likewise influence the rate of application. Possibly with some study, a rate of application based on the diameter of the tree, the area available for application, the soil type, and the root system of the tree can be formulated.

IMPORTANT SOIL FACTORS FOR PLANT GROWTH

Before definite fertilizer recommendations for individual plants are made, it is advisable to mention briefly some of the important soil factors. The readiness with which the mineral constituents are available to and usable by the plant is dependent upon various factors of plant growth. There are at least five important ones that must be taken into consideration. These are light, temperature, water, air, and nutrients. Of these, only light is not influenced in some way by soil conditions.

TEMPERATURE

Favorable soil temperature is needed for bacterial action, movement of water and nutrients, and root growth. Outdoors the only source of heat for warming the soil is the sun's rays. The extent of soil warming depends on the intensity of the sun's rays and the heat capacity of the soil. All gardeners know that the direct rays of the sun on a south slope make a warmer soil than the slanting rays on a north slope. The degree to which the sun's rays will heat the soil, however, depends upon how much water is in the soil. It has been shown that it takes two to four times more heat to raise a pound of water 1 degree than it does to raise the temperature of a pound of dry soil 1 degree. It is essential, therefore, to have soils well drained if they are to warm readily in early spring. In ordinary soils, the temperature is more favorable for root growth during the fall planting season than during the early spring.

WATER

The water-holding capacity of the soil is significant, since this quantity is an index of the amount of water available to the plant. The movement of water in soils is also of importance. If too much water is added to the soil, either by rainfall or by irrigation, the excess must drain away rapidly for the best plant growth. Since the plant root removes water from the soil, it is essential to know something of the rate of capillary movement of water.

In visualizing the make-up of a soil, it is apparent that it contains solid soil particles and pore spaces between these particles. A good soil contains about 50 per cent pore space, which is divided equally between small, or capillary, pores and large, or noncapillary, pores. The small pores hold water by capillary action and are responsible for the water-holding capacity of the soil. The large pores do not hold water but are responsible for the air capacity of the soil, as well as for soil drainage. The difference in the pore spaces between a sandy and a clay soil is easily understandable. A sandy soil has too many large pores and not enough small ones. Thus, it has a low water-holding capacity and a large percolation rate. In clay soils the reverse is true; they have a large water-holding capacity, low air capacity, and a low percolation rate. The ideal soil, providing the best conditions for plant growth, contains about 50 per cent solid particles, 25 per cent water, and 25 per cent air. Such a soil would have sufficient water-holding capacity, adequate drainage, and good aeration. The loam soils come closest to exhibiting these conditions. Some recent reports indicate that movement of capillary water even in good soils is too slow to supply the necessary moisture to growing plants over a distance of more than a few inches. Thus, roots develop in soils where usable water is present; water does not move to the roots. Extensive root distribution should be encouraged.

AIR

The factor of soil aeration cannot be overemphasized. A well-aerated soil should contain over 10 per cent of large pores on the basis of the total soil volume. If there are less than 10 per cent, root growth is not normal. Optimum conditions of aeration require that this percentage be nearer 20 to 25.

How does this optimum of 20 to 25 per cent air or oxygen actually check with conditions existing in clay soils? Compact clay soils often contain less than 5 per cent air pores. It is, therefore, obviously very important to increase the air capacity of heavy soils in order to obtain satisfactory growth, because it is just as necessary for plant roots to breathe as it is for human beings. The roots are continually using oxygen and giving off carbon dioxide. This carbon dioxide must leave the soil, and a new supply of oxygen take its place.

The air capacity and ease of aeration of soils can be improved by the addition of organic matter in the form of peat moss, barnyard manure, or artificial manure. In new lawns, aeration can be improved by plowing under a green manure crop, such as soybeans or some similar crop, the season before sowing the grass. Some tests have shown that well-rotted manure worked into the upper foot of a silty clay soil at the rate of a ton to each 1,000 square feet has increased the air capacity as much as 7 per cent. Four inches of cinders worked into the soil have increased air capacity as much as 10 to 12 per cent. Granulated sphagnum peat moss should be more effective than manure in maintaining proper aeration, and coarse sand could be substituted for cinders.

SOIL REACTION

The recent development of the rapid soil test kits has been a great aid to the landscape gardener. All too frequently have fertilizers been applied without any thought of what was already present in the soil. These colorimetric soil tests are easy to use and give a fairly accurate indication of the presence of the essential elements.

Tests of the reaction of the soil will give information regarding the availability of the nutrients in the soil to the plant. Although the reaction (acid or alkaline) of the soil is not the only factor influencing the availability of the nutrients, it is an important one. An acid reaction is necessary for adequate availability of all the essential elements except calcium and magnesium. Acidity is expressed in terms of pH. In the acidity-alkalinity scale, pH 7.0 represents a neutral reaction. Any pH number from 0 to 7 indicates an acid reaction, which decreases as the number increases. Any pH number from 7 to 14 indicates an alkaline reaction, which increases as the number increases. From the data available, it would seem that a reaction of the soil between 6.0 and 6.5 is the most favorable to maintain for the great majority of ornamental plants. Highly acid soils are necessary for most Azaleas and Rhododendrons and other ericaceous plants. Directions for acidifying soils are given in table 6.

TABLE 6.—Acidifying soils

The following approximate amounts of sulfur or aluminum sulfate per 100 square feet will be necessary to increase the acidity of a silt loam soil from:

	Sulfur	Aluminum sulfate
	Lb.	*Lb.*
pH 8.0 to 6.5	3.0	7.0
8.0 to 6.0	4.0	10.0
8.0 to 5.5	5.5	13.5
8.0 to 5.0	7.0	17.5
7.5 to 6.5	2.0	5.0
7.5 to 6.0	3.5	7.5
7.5 to 5.5	5.0	11.5
7.5 to 5.0	6.5	15.5
7.0 to 6.0	2.0	5.5
7.0 to 5.5	3.5	9.0
7.0 to 5.0	5.0	13.0
6.5 to 5.5	2.5	6.5
6.5 to 5.0	4.0	10.5

Among the shrubs preferring acid soil are *Azalea, Chionanthus* (Fringetree), *Cornus florida* (Flowering Dogwood), *Enkianthus, Ilex* (Winterberry), *Gordonia* (Franklinia), and *Symplocos* (Asiatic Sweetleaf).

A few woody ornamental plants seem to do better in a neutral or slightly alkaline soil. *Amorpha* (Leadplant), *Cytisus* (Broom), *Cercis* (Redbud), *Deutzia, Hypericum* (St. Johnswort), *Hydrangea, Indigofera* (Indigo), *Kolkwitzia* (Beautybush), *Koelreuteria* (Goldenrain-tree), *Laburnum* (Goldenchain), *Lonicera* (Honeysuckle), *Philadelphus* (Mockorange), *Symphoricarpos*, and *Syringa* (Lilac) are among this group.

Where necessary, ground limestone can be added to increase the alkalinity of the soil, as indicated in table 7.

TABLE 7.—Lime requirement of different soil types of same reaction

Present pH of soil	Pounds of agricultural ground limestone needed per 1,000 sq. ft. to raise—					
	Sandy loam soils—		Silt loam soils—		Silty-clay loam soils—	
	to pH 6.0	to pH 6.5	to pH 6.0	to pH 6.5	to pH 6.0	to pH 6.5
6.0	None	23	None	41	None	58
5.5	23	46	41	83	55	115
5.0	46	69	83	124	115	173
4.8	55	78	97	138	138	196

Definite soil and fertilizer recommendations are difficult to make for the various classes of plants because of the many variable conditions under which plants exist. Recommendations should be taken as standards and modified to fit the individual case. The following chart is prepared to give in a brief form the preferable soil type and fertilizer recommendations for many plant types. The provision of good drainage and aeration, an ample quantity of organic matter, and sufficient moisture should be foremost in mind in the selection or preparation of any soil for any plant. If these conditions are provided, most plants will do well in variable soil types and in soil reactions from slightly acid to slightly alkaline.

SOIL AND FERTILIZER CHART FOR WOODY ORNAMENTALS

STANDARD TREES

Soils

No specific soil type is required. Ample drainage from the bottom of the hole can be provided by using 4-inch agricultural tile or broken stone. Good compost soil or loamy topsoil with which has been incorporated peat moss or well-rotted manure is used about the roots of small trees or around the backfill of trees moved with a ball. Peat moss or manure can be used up to 50 per cent by volume; the amount depends on the soil type. Sand can replace up to one-fourth of the peat. Superphosphate at the rate of 5 to 10 pounds per inch in diameter of the tree trunk, and muriate of potash at the rate of 2 pounds per inch in diameter of the tree trunk, are best incorporated with the soil mixture at planting time. Trees should be planted slightly above the grade. The correct soil reaction must be ascertained. A few trees, such as the Honeylocust, Kentucky Coffeetree, and London Plane, do best in a neutral or alkaline soil. Such trees as the Sweet Gum and most of the Oaks do best in an acid soil.

Fertilization

TIME

Fall (October 1 to November 1) is preferred, although spring is satisfactory.

KIND OF FERTILIZER

12-6-4, 10-6-4, 10-5-2, and 8-5-3 are satisfactory. 25 to 30 per cent of the nitrogen should be of organic nature.

RATE OF APPLICATION

Small trees, less than 6 inches in diameter, require one-fourth pound of available nitrogen per each inch in diameter of the tree trunk; large trees, more than 6 inches in diameter, one-half pound of available nitrogen per each inch in diameter of the tree trunk. Examples: A 4-inch tree requires one-fourth pound per inch, or 1 pound, of available nitrogen. If a 10-6-4 formula is used, 1 pound is divided by 0.10 (10 per cent nitrogen). The result is 10 pounds, the amount of 10-6-4 required. A 10-inch tree requires one-half pound per inch, or

5 pounds, of available nitrogen. If a 12-6-4 is used, 5 pounds is divided by 0.12 (12 per cent nitrogen). The result is 41.6 pounds, the amount of 12-6-4 required.

FREQUENCY OF APPLICATION

Fertilizer should be applied every year to every 3 years, depending on the kind of tree and the growth response.

METHOD OF APPLICATION

Broadcast.—This method can be used for small trees or trees with low-hanging branches under which the soil can be worked. The fertilizer is hoed and watered in.

Aero-fertil.—Forcing the fertilizer into the soil by means of compressed air is probably the best method. If water can be added at the same time, it will be beneficial, at least under dry soil conditions.

Punch-bar.—This is the most common and economical method. If the holes are placed close together, the punch-bar method will prove comparable to the aero-fertil method. The fertilizer should be applied in holes distributed evenly beneath the spread of the branches and over an area beyond the spread of the branches. The radius of the area for small trees can be calculated by multiplying the diameter of the trunk in inches by one and a half or two. This calculation will give the radius of the area in feet. This calculation is for an unrestricted area of soil with no curbs or sidewalks interfering. Approximately 15 to 25 holes per 1 inch in diameter of the tree trunk are required. Holes should be made 15 to 18 inches deep with a soil auger or crowbar. The fertilizer, from one-third to one-fifth pound for each hole, mixed with compost soil or organic matter is placed in the holes, and the holes are capped.

EVERGREENS

Narrowleaf Evergreens

SOILS

Most narrowleaf evergreens do best in a deep and fairly light loam. Excellent drainage and aeration are important. Evergreens should not be planted too deeply; setting a little above normal grade is desirable. If the soil is of a light sandy nature or a heavy clay, a liberal amount of organic matter, preferably granulated peat moss, should be incorporated with it before the planting is done.

FERTILIZERS

10-6-4, 8-5-3, or 4-12-4 fertilizers, 2 to 4 pounds per 100 square feet of bed area each spring, are satisfactory. The fertilizer should be hoed or watered in. Care should be taken not to damage the roots in hoeing. Specimen plants of shrubby type require one-half to 1 pound per plant in the fall or early spring. Additional applications are made as soil tests indicate. Specimen trees require 2 to 2½ pounds per each inch in diameter of the trunk.

Broadleaf Evergreens

SOILS

Three soil factors are of prime importance, excellent drainage, ample organic matter, and an acid reaction for many types. In addition, soils should be relatively cool and moist. A normal light garden loam can be modified to give these conditions. Drainage can be provided by excavating beds to 2 feet and using tile or broken rock. Organic matter can be provided by adding acid peat moss or woods soil. A good mixture consists of 50 per cent light loam, 30 to 40 per cent peat moss, and 10 to 20 per cent acid sand. Since roots of most broadleaf evergreens are shallow, a 2-inch mulch of peat moss should be applied over the entire bed. The mulch should be stirred occasionally during the growing season. The acidity should be from pH 5.0 to 6.0 for plants which need an acid soil. The acidity of slightly acid or neutral soils can be increased by additions of fine sulfur or aluminum sulfate. The quantity of application should be based on soil tests. Directions for acidifying soils are given in table 6.

The following broadleaf evergreens are among those requiring an acid soil: *Arctostaphylos* (Bearberry), *Azalea, Calluna* (Heather), *Epigaea* (Trailing-Arbutus), *Erica* (Heath), *Galax, Gaylussacia* (Huckleberry), *Kalmia* (Laurel), *Leiophyllum* (Sandmyrtle), *Leucothoe, Pieris* (Andromeda), and *Rhododendron.*

FERTILIZATION

To poor soils which need additional fertilization, well-decayed manure, cottonseed meal, or tankage should be added. Tankage or cottonseed meal applied at the rate of 5 pounds per 100 square feet is excellent for small plants. For large plants, an 8-5-3 or a 4-12-4 fertilizer in which cottonseed or soybean meal is used to supply one-half to three-fourths of the nitrogen is satisfactory. The fertilizer should be applied at the rate of 2 to 4 pounds per 100 square feet of bed area. The amount is split into two applications, one made in early spring, the second after flowering. The fertilizer is watered in. For large specimen plants, the same rate of application as given for narrowleaf evergreens is followed.

DECIDUOUS SHRUBS

Soil

Soil requirements are not specific for most deciduous shrubs. Light loam to clay soils are satisfactory for most types. The soil should be well drained and contain ample organic matter.

Fertilization

Incorporation of superphosphate, 10 pounds per 100 square feet, and well-rotted manure is desirable before planting. 10-6-4 or 4-12-4, 2 to 4 pounds per 100 square feet of bed area, should be applied each spring. For specimen shrubs, 1 to 2 pounds per plant should be used. Further applications should be based on soil tests.

ROSES

Soils

Silt loam soils are favored but not necessary. Sandy loams can be used and silt loams are improved if sufficient peat moss (up to 50 per cent by volume) or other organic matter is incorporated. The addition of a liberal quantity will favor high moisture capacity, which is desirable during the summer. Soil should be thoroughly prepared. As for most shrubs, it is advisable to mix with the soil about 10 pounds of superphosphate per 100 square feet of bed area at the time of planting. A 4-12-4 or 8-5-3 fertilizer, 3 pounds per each 100 square feet, can be substituted for the superphosphate.

Fertilization

In the spring as growth starts, 4 pounds of superphosphate per 100 square feet can be applied. Potassium chloride, 1 ounce per 2 gallons of water applied to 12 square feet, is used 2 to 3 weeks after the superphosphate. Ammonium sulfate, 1 ounce per 2 gallons of water applied to 12 square feet, is added 1 week later and followed with similar doses once a week.

An alternate method is to use 4-12-4 or 6-8-6, 2 pounds per 100 square feet, two or three times during the season.

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