WHITTLESEY HOUSE GARDEN SERIES

Edited by F. F. ROCKWELL

SOILLESS CULTURE SIMPLIFIED

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SOILLESS CULTURE SIMPLIFIED

By ALEX LAURIE
Professor of Floriculture,
Ohio State University

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PREFACE

WIDESPREAD publicity has been given in the press, the popular magazines, and various periodicals to the so-called "new discovery" of growing plants without soil, *i.e.*, growing plants with their roots in a solution containing the needed elements for their development. Various names have been given to this method, such as "hydroponics," "chemiculture," "tray agriculture," "tank farming," "soilless culture," and "gravel culture." Much exaggerated publicity has given rise to the impression that a new era of agricultural development is about to be achieved—an era that bids fair to revolutionize all our present methods of crop production, if not, indeed, to dispense entirely with soil as a medium of plant growth.

Unfounded claims have been made concerning the ease of this new culture, implying that a few brief instructions would bring quick and certain success. Enormous yields of crops have been predicted from limited areas, and flamboyant advertising has suggested all sorts of possibilities. Grossly misleading statements have been circulated to the effect that any family could produce its own vegetables and flowers by installing a tank in the basement to supply the nutrition for plants, and electric lighting to provide the needed light. Skyscraper farms, apartment-house basements, and the roofs of hotels would in the future take care of all the needs of the occupants of such buildings!

Such unfortunate publicity is based on the assumed gullibility of the lay public, uninformed as it is concerning the basic processes that underlie plant growth. Much that has been written has come from the pens of promoters who have little actual knowledge but who are imbued with great enthusiasm—and who are inspired, in some instances, with visions of easy profits.

The object of this volume is to present the actual status of the subject; to disabuse the average person, the enthusiastic gardener or the commercial grower of false notions; and to discuss the real possibilities that the field of chemical plant culture promises. Many years' work in the attempt to apply the use of nutrient solutions in a *practical* way has given the writer a wide familiarity with the problems involved. Much more must be learned, however, before any absolute assurance of success may be guaranteed.

Success in growing plants depends upon knowledge of the functions of the soil, the factors that influence plant development, and the applications of the principles involved to practice. Although this book deals with methods of growing plants without soil, the fundamentals of growth in soil are first discussed, because the practices involved are similar and their thorough understanding is essential. Hence the reader will find the discussion useful in growing plants both in soil and without.

Grateful recognition is herewith tendered to all the graduate students and staff of the Department of Floriculture at Ohio State University, who have had a hand in the solution of the many problems involved in this method of growing plants. Particular appreciation is extended to G. H. Poesch, Arnold Wagner, D. C. Kiplinger, William Robinson, J. R. Culbert, Raymond Hasek, and Fred Petri, whose assistance has been invaluable. Since the advocacy of this method for commercial use, much added information has come from Yoder Brothers, Barberton, Ohio; A. F. Amling Company, Maywood, Ill.; Ross Churchward of Columbia Station, Ohio; Joseph Fueglein of the Joseph H. Hill Company of Richmond, Ind.; Charles Bancroft of Mills Roses, Richmond Hill, Ontario; and George J. Ball of West Chicago, Ill.

ALEX LAURIE.

COLUMBUS, OHIO.

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EDITOR'S FOREWORD

NOT in many years has any subject in the world of horticulture caused such a storm of discussion as the new technique of growing plants by means of feeding them with chemical "nutrient solutions" applied in water or some other soilless medium, instead of growing them in soil in the old-fashioned way.

Unfortunately this whole subject has been very much muddied up by the grossly extravagant claims sponsored by the more ardent of the followers of this new method, especially those commercially interested. Newspaper pieces illustrated by an "artist's conception" of the housewife of the future gathering her home-grown fresh vegetables from a garden in an icebox-like receptacle in the kitchen wall have been presented in all seriousness; articles in magazines whose editors should know better have shown little more restraint.

It is high time that someone who can speak with the voice of authority, from a rostrum not propped up by commercial interests, should give us an unbiased account of the *facts*, so far as we now know them, concerning this new science which, for want of a better phrase, we call chemical plant culture.

Professor Laurie is eminently fitted to give us this account in the present volume, and he has done it well. From a wide experience of many years, both in the experimental field and in that of practical application on a large scale of this new technique, he presents the results of his observations. Without making any foolishly extravagant claims, he sets forth clearly the benefits that may be expected from this new method of culture. And after discussing the theories involved, and giving a history of the experimental development, he presents in detail the different methods that are giving practical results.

But *Soilless Culture—Simplified* is much more than a treatise on the mechanics of growing plants without the use of soil. The information so clearly presented in it is of immeasurable value to every grower of plants, even though he may have little interest in "water," "sand," or any other type of soilless culture. He is vitally concerned with the principles of plant nutrition, and the problems of plant feeding; and to these problems the reader will find practical and up-to-the-minute answers in Professor Laurie's lucid text.

In fact, I think it is now safe to make the statement that, so far as the amateur is concerned, the greatest benefit to be derived from all the experimenting that has been going on in the culture of plants without soil will be an increased and more accurate knowledge of how to grow them successfully in soil.

With a full realization of the importance of these discoveries, Professor Laurie has been careful to take every advantage of the new information made available and to present it in a way that any beginner can grasp. Hence *Soilless Culture—Simplified* is a volume that every grower of plants will wish to add to his working library.

F. F. ROCKWELL.

FIG. 1.—The wonders of soilless plant culture—as often represented.

SOILLESS CULTURE SIMPLIFIED

Chapter I

HISTORY OF THE SOLUTION-CULTURE METHOD

DESPITE claims concerning the recent discovery of that new "marvel of science" the solution-culture method of growing plants, actually the first recorded experiment was made in 1699 by Woodward, who grew spearmint in several kinds of water. But so little was known then about the nutrition of plants that practically no value could be secured from these tests except his statement that "earth, and not water, is a matter that constitutes vegetables."

Very little of value was found until the early part of the nineteenth century, when Jean Bousingault, a French chemist, began his experiments with plants grown in sand, quartz, and charcoal, to which solutions of nutrient elements were added. In 1840 Liebig[1] published his findings and theories dealing with the fact that plants are made up of chemical elements secured from the air, soil, and water. His further conclusions were that water was essential for plant growth; that the

[1] Liebig, Justus von, *Chemistry in Its Application to Agriculture and Physiology* (English translation), 401 pp., John Wiley & Sons, Inc., New York, 1861.

dry matter was made up of carbon, oxygen, and hydrogen; that carbon and oxygen came from the air and hydrogen from the water; that plants also contained nitrogen, phosphorus, potassium, and calcium. This mineral-nutrition theory was substantiated by the findings of Bousingault, and thus we have the first definite attempts to grow plants in nutrient solutions instead of soil. Salm-Horstman (1856–1860) improved on the actual method of procedure.

Sachs[1] in 1860 dispensed with the use of various inert media and began to grow plants in water to which various needed elements of plant growth were added. He was followed by Knop, Tollers, Pfeffer, Crone, Tottingham, Shive, Hoagland, *et al.* Essentially the original solutions suggested by these workers are still used, although modifications have been developed.

For many years the method of studying plant nutrition was employed in laboratories throughout the world; but no definite attempt to apply the information gained to the practical growing of plants was made until 1921, when Pember and Adams (at Rhode Island Agricultural Experiment Station, in studying the influence of physical factors and various elements on the growth of carnations) found that carnations would grow in sand to which nitrogen, potassium, and phosphorus were added. The carnations not only grew but produced a greater number of good-quality flowers than those grown in soil, to which similar materials

[1] Sachs, Julius von, *Lectures on the Physiology of Plants*, 836 pp., Clarendon Press, London, 1887.

and manures were added. Likewise, additions of commercial peat to sand affected the plots beneficially, a fact that these workers believed to be due to the prevention of excessive leaching of the added nutrients.

Biekart and Connors[1] in 1935 reported on a series of tests started in 1927, using sand for commercial growing of carnations. Their summary and conclusions follow:

"The production of quality carnations in sand with nutrient solution and in quantities comparable with those grown in composted soil seems to be thoroughly practical and economical.

"The kind of sand is immaterial as long as it is medium coarse. Two types were used in these tests: one, a yellow, unwashed sand with some silt and a rather high proportion of gravel; and the other, a washed white sand with little gravel. Washed sand required more frequent watering than unwashed sand, but it is advisable to use washed sand.

"Sand in use for six years produced just as good growth and as many flowers as did fresh sand or composted soil.

"The pH of the sand in carnation culture in the four-salt solution, as applied in these experiments, was very stable and varied only between 4.8 and 5.2 in mid-winter and between 5.2 and 5.6 in the spring.

[1] Biekart, H. M., and C. H. Connors, The Greenhouse Culture of Carnations in Sand. *New Jersey Agricultural Experiment Station Bulletin* 588, p. 24 (1935).

"Unwashed sand required no more water than soil because it formed a natural mulch which prevented surface evaporation through capillary action.

"Nutrient solutions in sand produced flowers of the same quality as did soil in regard to stem length, vigor of stem, and size and keeping quality of the flower. The number of flowers was about the same as on soil, when various varieties were considered.

"Per 50 gallons of water, the following amounts of salts were used:

Ammonium sulphate	30 g.
Potassium phosphate monobasic	57 g.
Magnesium sulphate	114 g.
Calcium nitrate	486 g.

"Plants grown in sand were better controlled in their rate of growth than those grown in soil, because the sand was flushed more effectively and nutrients that were applied were immediately available. These facts were of great importance during dark weather when the days were short and during a period of heavy production in the spring when an extra supply of nitrate was helpful.

"Pot-grown plants when benched were inferior to field-grown plants when the former were much smaller and benched at the same time as the latter. Growth development of plants grown in sand in 4-inch pots for the season 1934–1935 seems to indicate that these plants bid fair to surpass the field-grown stock if they are benched one month earlier than the latter and grown in the open during the early summer.

"After the plants were well established and growing vigorously, the application of 2 pints of nutrients to each plant every week was of little more benefit than a pint application.

"Rust and spider mites were less noticeable on the plants grown in sand than on those grown in soil. Associated with the lack of organic matter in the sand, there was less rust; in the sand plots there were also fewer spider mites, possibly because of the more even water supply. It is a well-known fact that plants that occasionally suffer from lack of moisture, which is easily possible in soil, are first infested by this pest.

"Branch rot was more common in one variety than in another and was more serious in the soil than in the sand. Sand sterilization is not necessary unless the variety grown during the previous season was noticeably affected by this disease.

"The carnation did not require the addition of iron to the nutrient solution in order to prevent iron chlorosis.

"The carnation by actual analysis was found able to absorb and store large quantities of nitrate nitrogen which may be assimilated over a long period."

In 1929 the author[1] began a series of tests with sand for the culture of carnations, snapdragons, sweet peas, roses, and many other miscellaneous greenhouse crops.

[1] Laurie, Alex, The Use of Washed Sand as a Substitute for Soil in Greenhouse Culture, *Proceedings of the American Society*

In place of using nutrient solutions, the chemicals were applied in dry form in order to approximate as closely as possible commercial practices. The conclusions drawn from these tests were:

1. Good-quality roses, chrysanthemums, snapdragons, stocks, carnations, and calendulas can be grown in either pure sand or half sand and half peat to which nitrogen, phosphorus, and potassium from commercial carriers are added regularly.

2. Low-ratio nutrients (1-4-1) composed of ammonium sulfate, superphosphate, and potassium chloride applied to plants at 2- to 4-week intervals, depending upon the season of the year and at the approximate rate of 2 pounds to 100 square feet, are sufficient to produce plants comparable in quality to those grown in good soil.

3. Sand plots require more water than soil only during the summer months.

4. Pot plants such as cineraria, fuchsia, calceolaria, hydrangea, calla lily, and various spring bulbs can be grown to excellent size and quality in sand to which nutrients are added regularly.

5. Hydrangeas and fuchsias responded best when aluminum sulphate was added to the sand to bring the reaction to pH 5.

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for Horticultural Science, 28: 427–431, 1931.

Laurie, Alex, Further Studies of the Growth of Ornamental Plants in Quartz Sand, *Proceedings of the American Society for Horticultural Science*, 29: 537–539, 1932.

6. Sand is so much heavier than soil that it is not a suitable medium for growing plants in pots, making the pots too cumbersome to handle.

7. The shifting of pot plants growing in sand to pots of larger size is more difficult than shifting soil-grown plants, because the sand is not so cohesive as soil.

8. Certain economies are effected by the use of sand. Yearly changing of soil in benches is eliminated. Variations in structure and nutrient content of composted soils are avoided, which leads to more standardized practices in nutrition. The problems of aeration and moisture are reduced to a minimum. Sterilization is simplified, and accumulations of soluble salts prevented.

Despite these advantages, the use of sand as a substitute for soil has not met with favor by growers, largely because it involves as much labor and necessitates greater care in handling. However, for growing seedlings of various horticultural plants, the sand-culture method has possibilities as indicated by Dunlap.[1] This is discussed in detail in Chap. VII.

In 1936 Eaton[2] developed an automatic system of sand culture which supplies the nutrients under pressure from lines of perforated pipe laid on the surface of deep beds of sand in watertight containers. The solution is

[1] Dunlap, A. A., Sand Culture of Seedlings, *Connecticut Agricultural Experiment Station Bulletin* 380, 1936.

[2] Eaton, F. M., Automatically Operated Sand Culture Equipment, *Journal Agriculture Research*, 53: 433–444, 1936.

pumped into the beds periodically and then drains back into a tank.

The present systems of "gravel culture" are based largely upon this automatic flooding of benches. The original suggestion emanated from R. B. Withrow of Purdue University in 1936. It was also used, the same year, by workers at the New Jersey Agricultural Experiment Station and the author and his assistants at the Ohio Agricultural Experiment Station. The gravel-culture system differs from the automatic sand-culture method largely in the matter of size of particles of inert materials used to hold the plants in place and the composition of these particles.

The commercial application of water culture was developed by W. F. Gericke of the University of California in 1929 and has since been tested by many research workers and exploited by persons whose imagination has run wild and whose enthusiasm has got the better of common sense.

This brief account brings us to the present time, with many modifications in the mechanics of application and of nutritional solutions. These have helped in placing the method of soilless plant growth on a more sound basis and one devoid of fanfare and unreasonable claim or expectations.

Chapter II

THE SOIL AND THE FUNCTIONS OF ELEMENTS

The Soil

We have become so accustomed in everyday life to looking upon soil as the source of our existence and have such a deeply rooted conviction of its indispensability that a transition from this conception to that of the possibility of attempting to grow plants without the soil is difficult. Consequently it is, in presenting this new idea, essential to discuss briefly the conditions of soil as they affect plant growth and then translate these in terms of plant growth without the soil. In the end the two methods are similar in effect.

We may picture to ourselves the soil as an immense commercial factory. The raw materials are the undecomposed particles of rock and organic matter; the workers are the various forms of microorganisms (bacteria, fungi, molds, and their close allies); the supervisors, or managers, are aeration, moisture, heat. Without this teeming multitude of working organisms the soil would really remain as inert as it looks to the eye. Without the complete domination and continued presence of the supervisors the work would cease.

Thus the soil, with its particles of different sizes in varying stages of granulation, presents a storehouse of materials, raw and in gradual stages of decomposition, which are used by plants in growth provided the proper factors are present. These factors are the presence of sufficient organic matter; water; air; suitable temperature; and the supply of plant nutrients, or "foods."

Organic Matter

The organic matter in soils originates from the presence of roots and tops of plants, the remains of animals, and the decomposition of microorganisms. Since much of this organic matter is composed of plant remains, its constituents are proteins, cellulose, waxes, oils, and others. The importance of these compounds as a source of soil fertility has been known for many years. The physical structure of the soil is bettered by the presence of organic matter, which separates the soil particles or cements them together to form granules, producing mechanical conditions that aid in drainage and aeration. Chemically, organic matter is a direct source of nitrogen and other nutrients, and indirectly it renders more available such elements as calcium, magnesium, iron, and phosphorus, besides producing humic acids which have their effect upon the soil reaction and the increase in availability of the trace elements. Furthermore, organic matter functions as a source of carbon dioxide. The organic colloidal compounds have a tendency first to "fix" calcium, magnesium, potassium, and phosphorus and later to release these in a slow but continuous supply to the plants. The microorganisms needed for the various changes in the soil that transform insoluble elements into available materials are increased by the addition of organic matter. These organisms under proper conditions liberate available nitrogen and stimulate growth. Finally, the value of organic matter for conserving moisture in the soil cannot be overlooked.

Three important sources of organic matter are available for plant culture: stable manures, green manures, and peats. Stable manures are best if obtainable. If not, it should be recognized that commercial fertilizers alone cannot be substituted for manures; that commercial fertilizers are most effective when organic matter is present; and that a substitution for manure may be made through the incorporation into the soil of green or partially matured crops (green manures) or peats.

Artificial manure is as satisfactory as stable manure and may be made quickly, provided that certain fundamental precautions are observed. Any plant residue may be used—straw, hay, leaves, vegetable litter. To produce such manure, the decomposition of the plant residue must be brought about through bacterial action, which is hastened when sufficient moisture is present, together with high temperature and adequate nutrition for the organisms. Hence the best time to make artificial manure is in the spring as the temperature rises and rains are reasonably abundant. The actual operation consists of spreading the litter, or plant refuse, used in layers about 6 inches deep, applying a fertilizer (which may consist of 150 pounds of cyanamid and 25 pounds of superphosphate or a mixture of 60 pounds of ammonium sulphate, 30 pounds of superphosphate, 25 pounds of potassium chloride, and 50 pounds of agricultural lime) to every ton of straw or leaves or litter. These mixtures should be spread thoroughly over the 6-inch layer and watered well. The pile may be continued until a height of 4 feet is reached. The top should be dished in, *i.e.*, built up higher at the edges, to allow water to collect on the surface and seep down through the heap. With regular applications of water, naturally or artificially, such a pile should decompose during the season and provide an excellent substitute for manure with the added advantage of being free of weed seeds and disease organisms which ordinarily go through the digestive systems of animals unimpaired and frequently cause trouble when fresh stable manure is used.

Green manures ordinarily used are soybeans, sweet clover, alfalfa, hairy vetch, buckwheat, and rye. These should be plowed or spaded under in the immature stage so as to provide the greatest returnable quantity of nitrogen and minerals to the soil. These green manures are valuable not only because of the organic matter returned to the soil but likewise because the penetration of the soil by roots aids in the physical structure of the soil and distributes such a slowly moving element as phosphorus through the deeper layers of soil, thus bringing it into more intimate contact with roots of the crops that follow.

Peats and peat mosses, both domestic and foreign, are likewise useful as additions of organic matter. Contrary to the common notion, peats not only increase the water-holding capacity of the soil but also change its structure and its reaction and add nitrogen.

The importance of the organic matter in the soil thus cannot be overlooked. It provides the essential factors of aid in nutrition—water-holding capacity, temperature, and aeration. All these, as we shall see, are supplied artificially, but with the same end in view, in the sand, gravel, or water cultures in which we are interested.

Water Supply

Plants grow luxuriantly only with a plentiful supply of water. Its absorption by the plant is essential for the maintenance of cell turgidity and the supply of the dissolved nutrients in the soil. The condition of the soil and air in this respect determines the amount of water absorbed and the rate of its movement through the plant. The leaves of plants are continuously giving off into the air water vapor (transpiration) which is made good by the intake of water through the roots. By increasing the humidity in the air, as is frequently done in the greenhouse, the process of transpiration is checked; and if this checking continued for long periods of time, fresh supplies of water are withheld from the roots, the cells lose their turgidity, and finally growth ceases. Practically, this does not mean that the common practice of syringing and wetting down walks in the greenhouse should be eliminated, but it does mean that judgment must be exercised in the maintenance of humidity in the air.

The water supply to the plant should be continuous, and any reduction of it frequently causes wilting. If continued long enough, wilting may have serious consequences. In the early stages, lack of sufficient water merely causes slowing down of growth; but in later stages of maturity, premature ripening and hardening may result. Constant low levels of water will cause dwarfing of plants and reduce the size of leaves, fruits, and flowers. With increased water supply the foliage becomes larger, and the root system more extensive up to the point where an oversupply of water results in the tendency of the roots to become less fibrous.

The influence of moisture on photosynthesis—the manufacture of food in leaves—is very great. When water supply at the roots is limited, food manufacture decreases. Furthermore, any wilting of the plant may be a sufficient check from which the plant never recovers completely. This is especially important during the hours of sunshine when, normally, food is produced. A uniform soil moisture is good insurance for maximum growth.

Excess moisture, on the other hand, has a retarding influence, due to displacement of air in the soil. It reduces the oxygen to such an extent as to prove injurious. It is often noticeable that plants are wilting, although the soil may be saturated. Under such conditions the root hairs fail to function, die back, or die off entirely, and little absorption takes place to compensate for the evaporation from the leaves. Mulches and the shading of glass in greenhouse culture have a tendency to conserve moisture without reducing the aeration of the soil.

In actual practice it is difficult to maintain an absolute uniformity of soil moisture, but it may be done by heavy watering (1 gallon to 2 square feet in 5 to 6 inches of soil) and then allowing the soil to dry out enough to cause the formation of new growing points and root hairs—accomplished by the presence of sufficient air. Such practice is common commercial procedure. The cultivation of soil may be considered detrimental from the standpoint of root breakage; but when the soil becomes so packed as to act as an impervious cover, then such cultivation becomes almost a necessity. We pay entirely too little attention to the air in our soils, and many plant troubles may be ascribed to that cause.

It is interesting to note that well-fertilized soil reduces the water requirement of plants. The explanation is simple. If a soil is poor, some mineral element may be lacking; and as the supply of such an element nears exhaustion, growth practically ceases. Transpiration, however, continues, thus requiring more water for the plant in proportion to its growth. It may be argued that more moisture is lost from a plant growing in fertile soil than from a similar one growing in poor soil, owing to the fact that more foliage is produced in the rich soil. Yet actually, per unit of growth, less water is needed. This emphasizes the importance of maintaining fertility of the soil.

To secure the best results from soil moisture in the greenhouse, the temperature of the soil should be as high as that of the greenhouse air. Breaking down of organic matter and quicker absorption are helped by increased temperature. The application of cold water during the winter has an inhibiting effect on the absorption both of water and of nutrients. This is particularly noteworthy in solid or ground beds. Any method of increasing the soil temperature is desirable—whether by heating the water previous to application or by heating the soil.

As to water itself, hard, alkaline water will gradually tend to raise the alkalinity of the soil, sometimes to a detrimental point. Acidifying water by means of acids—sulphuric, phosphoric, or nitric—may be necessary, and it is practiced where conditions warrant. Chlorinated city water has little detrimental effect, since at the rate of one part per million it would be almost impossible to drink it, and the danger point for plants is actually not reached until the concentration rises to 5 p.p.m. or more. Besides, since most soils are high in humus, much of the chlorine is absorbed and becomes inert.

It is interesting to note that rain water contains enough nitrogen to add about five or six pounds of this important element to the acre annually. Likewise, many city water systems will show a content of nitrogen up to 30 p.p.m.

Air Supply

The air supply in the soil is essential for the development of the roots, the life of many organisms, and the oxidation processes that make available the needed elements. In addition to the oxygen supply from the air, carbon dioxide is likewise needed for its solvent action on soil particles. This aeration of the soil is produced by structural or mechanical conditions, *i.e.*, whether the soil is loose or compact, hard or friable. The production of a granular state of the soil particles is ideal and is secured by additions of organic matter, proper tillage, the use of calcium, and proper drainage. This essential factor (aeration) is one of the important reasons why plants succeed so well in "gravel culture," and many recent studies of the porosity of the soil tend to show the great need of attention to that detail.

Root activity is dependent not only upon the proper supply of nutrition but to a large extent upon the structure of the soil, which means the arrangement of the particles and their granular construction. This arrangement is allied with the porosity or air spaces and thus with aeration. Furthermore, it is important because of the relationship of the air and water in the soil. There are pores so large that they hold no water but only air; and there are pores small enough so that they retain water only, to the exclusion of air. Practically we know that sandy soils, which contain large pores due to the large size of the particles, hold water poorly and contain excesses of air. On the other hand, clay soils, because of the fine particles and small pores, hold large amounts of water, and therefore these soils retain little air. Silt and loam soils are more ideal, containing both large and small pores, so that we have a satisfactory balance between the necessary air and water. Large pore spaces, as in sand, which hold no water, and extremely small pores in clay, which retain no air, are both detrimental to the production of an extensive root system. Such a root system is needed to provide a large zone for feeding roots and the intake of water. Capillary action alone is not sufficient for the provision of water; it should be supplemented by the proper structure of the soil. In actual practice this porosity may be obtained by adding such inert matter as cinders, gravel, or sand to soils that have a tendency to be so fine particled as to preclude the possibility of proper circulation of air.

Nutrient Supply

Plants, if they are to develop properly, must be supplied with a sufficient quantity and the correct quality of nutrients. Changes in the need for fertilization may be due to variations in the growth of plants under different environmental and soil conditions or to the fact that various plants react differently to the same fertilizer elements. Thus, fertilizer recommendations, even made after considerable experimentation, can apply specifically only to limited conditions.

All these introductory remarks point to the fact that it is best to look at the fundamental requirements of the plant—the influence of the essential elements upon the development of plant tissue—and then try to adapt the fertilizer recommendations to the soil and environmental conditions under which it is growing.

The Essential Elements

With these facts in mind we may consider the essential elements, their influence upon plant growth, and materials common in the trade that carry these elements.

Almost any gardener these days is more or less acquainted with the fact that ten elements are considered essential for plant growth. Of these ten, only nitrogen, phosphorus, and potassium are indicated as present in all so-called "complete" fertilizers. These three are the ones most often limiting to plant growth. Carbon and oxygen in ample quantities to assure growth are normally present in the atmosphere. Calcium, iron, magnesium, and sulphur may be deficient in certain soils and must be added to the complete fertilizer or supplied as separate salts. At times they are present as impurities in the fertilizer carriers used.

Recent experimental evidence shows that such "trace" elements as boron and manganese, and possibly copper and zinc, are necessary, at least in very small quantities, for the proper development of some plants. As a consequence, small doses of these elements are now being included in some commercial fertilizers.

Influence of Essential Elements on Plant Growth. These essential elements exert various influences upon plant growth, some of them not clearly understood and very difficult to detect. With the influence of the various elements in mind, we have some basis for fertilization recommendations. In other words, certain reactions may with reasonable certainty be expected from specific applications.

Carbon, hydrogen, and oxygen are all essential for the manufacture of carbohydrates, fats, and proteins. Although these elements are not added in fertilizers, they are essential for growth. We expect applications of *nitrogen* to stimulate succulent growth and delay maturity. It is the element that gives us the "push" in plants. It should be added at periods when the plant roots are active and can readily absorb it. Overdoses may easily cause burning, so it should be handled carefully. Early applications will allow proper maturity of the plants by fall, and delayed applications should not be used under any conditions with plants that are inclined to be tender or to mature late in the season.

Nitrogen

Table I illustrates the various carriers of nitrogen, their comparative contents, their availability, and their retention by the soil.

Phosphorus

Phosphorus keeps a check on the activities caused by nitrogen in that it hastens maturity, stimulates flower and seed production, and aids root development. It acts in cell division and formation of chlorophyll. Since it penetrates the soil slowly when applied to the surface, it should be incorporated thoroughly with the soil at

TABLE I
NITROGENOUS CARRIERS

Material	Nitrogen, per cent	Relative availability on basis of 100	Acidifying effect on soil	Retention by soil
Urea	46	90	Acid	Medium
Ammonium nitrate	35	95	Acid	Low
Ammonium sulphate	21	90	Acid	Medium
Cyanamid	22	90	Alkaline	Medium
Calcium nitrate	17	100	Alkaline	Low
Sodium nitrate	16	100	Alkaline	Low
Ammonium phosphate	11	90	Acid	Medium
Blood	10	80	Acid	High
Tankage	6	70	Neutral	High
Cottonseed meal	6	70	Acid	High
Fish meal	5	70	Acid	High
Activated sludge	4	70	Acid	High
Steamed bone	2	70	Alkaline	High
Tobacco	2	70	Alkaline	High
Garbage tankage	2	30	Alkaline	High
Peat	2	20	Acid	High

the time of bed preparation; or if applied later, it should be worked into the soil as thoroughly as possible.

The fact that the majority of our soils are naturally low in phosphorus necessitates its use in the making of composts. It is valuable to the plant in developing better root systems, assisting quicker maturity, aiding in general growth, and acting as a balance wheel for the nitrogen supply.

Phosphorus is sold as either superphosphate (20 per cent phosphorus); treble phosphate (45 per cent phosphorus); ammonium phosphate (11-48-0); or bone meal (23 per cent phosphorus), raw or steamed.

Bone meal should be finely pulverized for best results. This is feasible only if the bones have been subjected to steaming, so as to remove the fatty substances in them. Steamed bone meal contains about 1 to 1½ per cent nitrogen, whereas the raw bone may carry as high as 3 per cent. Which to use becomes a question; the greater amount of nitrogen in raw bone is balanced by the better availability of phosphorus in the steamed bone meal. Bone meal is not soluble in water but becomes soluble as the organic acids in the soil act on it. The phosphorus in bone meal is in its least soluble form, tricalcium phosphate, requiring considerable time to change over to the soluble forms. In general, however, the phosphorus in bone may be considered less soluble than in the superphosphate. In acid soils bone meal may have a better effect than superphosphate; but where adequate amounts of calcium are present, superphosphate is more satisfactory than bone in spite of its content of nitrogen as an added factor of value. Bone meal has a definite alkaline effect on the soil, but its use for such a purpose is not economical.

Superphosphates are soluble in water and hence provide quicker action than bone. This is particularly true of the treble phosphate. Additions of lime cause the reversion of the soluble monocalcium and dicalcium forms (as found in superphosphate) to tricalcium form, but even under such circumstances the phosphorus is still as quickly available as in the form of bone meal. The chief disadvantage is the fact that under very acid conditions superphosphates are not so satisfactory as bone meal. The differences in price between the materials should be given consideration when purchased—the superphosphates being much cheaper even when the nitrogen of bone is considered.

Ammonium phosphate is the most soluble form of phosphorus and, where both nitrogen and phosphorus are desired, makes the most satisfactory material of all the phosphates. In the form of Ammo-phos (11-48-0) or in the complete fertilizer Nitrophoska (15-30-15) it is exceptionally satisfactory.

Monocalcium phosphate (food grade), which contains 55 per cent phosphoric acid and is being used in gravel-culture solutions, is too expensive for average greenhouse or outdoor soil application. It is quite highly soluble in water.

Availability of Phosphorus. Fineness of grinding is important in such phosphorus fertilizers as bone, to permit each individual particle's being in contact on all sides with soil and later with root hairs. Such fineness is not desirable in the soluble phosphates, even though they may change over to a somewhat insoluble form upon contact with soil moisture. This form becomes soluble through the action of various organic acids in the soil, so that at least a portion may be used by the plant.

Phosphorus is utilized by the bacteria and fungi of the soil and may be tied up for a period but later is released for plant use in a manner similar to that of nitrogen when straw mulch is applied. The loss is only temporary. The spread of roots through the soil causes phosphorus availability, as certain solvents are released by the roots in contact with particles of phosphorus. Hence it is very important that phosphorus, in the form of bone or superphosphate, be thoroughly mixed with the soil and particularly in the areas where roots abound. The solubility of ammonium phosphate will force its passage to greater depth than other forms of phosphorus. The rate of phosphorus penetration through the soil is only about ½ inch in depth per year; hence any surface applications are of little value. Mix bone or superphosphate with soil whenever possible.

Granulation of Fertilizers. It was mentioned previously that superphosphate should not be used in fine form, and this is also true of ammonium phosphate. Granular materials permit greater ease in application. They have much less tendency to stick together. Likewise the granules expose less surface to the surrounding soil, thereby reducing the amount of fixation (insolubility) of phosphoric acid by the soil.

Applications. Superphosphate (20 per cent) and bone meal may be used at the rate of 5 pounds to 100 square feet, preferably as mixtures in the soil. If applied to the top, they should be worked in if possible. The beneficial effect from surface applications of bone meal is due to the nitrogen content which, however, is quickly dissipated. If an organic nitrogen fertilizer is desired, tankage is the most preferable form. Ammonium phosphate could be used as a top dressing at the rate of 2 pounds to 100 square feet, and Nitrophoska at the rate of 1 to 1½ pounds to 100 square feet. Apply all fertilizers to moist soil and water in.

Potassium

Potassium or potash is usually a general conditioner, aiding in the formation of starches and sugars and their transportation within the plant. It is influential in overcoming succulence and brittleness; it hastens maturity of the plant and intensifies the color of the flowers. It has been suggested as aiding in disease resistance as well as in seed production. Thus, taken together, these three materials—nitrogen, phosphorus, and potassium—aid in most of the normal reactions of the plant from seedling stage to maturity and the production of flowers and fruits.

Many of our cultivated soils, particularly sands and peats, are lacking in sufficient quantities of potassium. Even in clay and silt soils, continual use without the compensating additions of manures or leguminous cover crops causes potash depletion, which results in unsatisfactory growth. It is known that disease susceptibility is increased when potash is lacking; that production decreases; that during dark days of winter, blindness of wood increases (probably as a result of the theory that to some extent potassium compensates for lack of sunlight in photosynthesis); and that color is not so intense; hence the use of potassium is to be recommended.

Owing to the fact that potassium is held by soil particles and thus is not readily leached, apparently large quantities would be available to the plant. Yet actually a comparatively small percentage is available. As a consequence it has been found that to maintain a high level of this element, frequent applications are necessary. Thus, if our nitrogen-phosphorus-potash-calcium relationship is maintained at 25 to 50 p.p.m. (nitrogen) = 10 p.p.m. (phosphorus) = 40 to 80 p.p.m. (potash) = 150 p.p.m. (calcium), it would be necessary to add potash at more frequent intervals than nitrogen which becomes more readily available. In the majority of our soils this is frequently necessary.

It is interesting to note that a soil high in colloidal matter (fine particles of soil of gel-like nature to which the property of adsorption is attributed) may come to such a shortage of the potassium necessary for its maintenance that when potash is added little or no effect is produced because of competition between the soil colloidal matter and the plants. Thus frequently a heavier application of potash may be required on clay soil than on sand, in spite of the fact that clay soils are usually considered to have more potash than the sandy types. Considering all these matters, the use of potash cannot be overlooked. Likewise, it must be borne in mind that growers of bygone days did not seem to need to apply potash; they were content with the use of manures and bone meal. Therein lay the story: First, the soils themselves—more virgin than now—contained enough potash; second, manure supplies potash in large amounts; and, third, the calcium in bone as well as its nitrogen had and have a capacity to liberate potassium. Thus frequently when we apply lime or nitrate of soda we liberate potash, but a limit is eventually reached, and replacements must be made.

In what forms should potash be applied? One of the best sources is unleached wood ashes containing 3 to 10 per cent. However, since about 50 per cent of the ashes is in the form of lime, on neutral or alkaline soils wood ashes may become detrimental.

Other usable sources are tobacco stems or dust (3 to 5 per cent), flue dust from cement industry (10 per cent), flue dust from iron blast furnaces (16 per cent), waste from sugar-beet factories (16 per cent), seaweed (28 per cent), wool washings from wool industry (10 to 40 per cent). The usual forms, however, are potassium chloride (muriate of potash), potassium sulphate, and occasionally in combination with nitrogen as potassium nitrate (now frequently sold as a product called "Potnit," made by treating potassium chloride with nitric acid). Incidentally, our needs for potash can readily be taken care of in our own country. In California and New Mexico much potash is produced; and New Jersey, Delaware, Maryland, and Virginia have enormous deposits of such potash-bearing rocks—feldspars, potash shales, alunite, leucite—from which potash can be extracted with ease.

Potassium chloride is the form usually preferred, although potassium sulphate may likewise be used. Either one is used ordinarily at the rate of 1 to 2 pounds per 100 square feet of bench. Where magnesium is lacking in the soil, potassium-magnesium sulphate may be substituted. Since the first two mentioned contain about 50 per cent potassium, other materials bearing potash could be used at the rate of 5 to 6 pounds to the 100 square feet, and tobacco could be used in even greater amounts, except for its tendency to hold moisture when used too heavily and likewise because of its nitrogen content. (Therefore it should be used more frequently but sparingly.)

In testing for potash by means of the quick tests on the market, it should be remembered that if a high test for ammonia is shown (50 p.p.m.) the reading for potash will be hard to make, so it is always best to test for ammonia first to make sure that no error is later made in potash determination.

Potassium is available to plants from the soil when it is in solution and also when it is held in a replaceable form. In the replaceable form the potassium is adsorbed on the surfaces of the clay and organic matter particles. The potassium held in this manner is not readily removed from the soil by leaching with water. However, if the water should contain any salt material dissolved in it, the salts would loosen the potassium from its adsorbed position, causing the potassium to be carried out of the soil and lost. The chemists speak of this as an "exchange process."

Ammonium sulphate dissolved in water acts as a salt that causes potassium to be exchanged or replaced and leached out of the soil. Wherever ammonium sulphate is used frequently, it is well to be aware of the possible potassium deficiency that may result from this exchange and leaching process. To overcome this difficulty it is merely necessary to add potassium as muriate of potash at frequent intervals depending upon the extent of leaching that has taken place and the amount of sulphate used.

If the plant tissues are tested for the presence of soluble potassium and it is found that only a small amount of potassium is present, the plant may be starving for potassium or may be growing in a soil unbalanced with respect to nitrogen and potassium. To such a soil it would be advisable to add some muriate of potash. The potassium can be added in solution in a way similar to that by which the ammonium sulphate is added, for it is readily soluble. The newly supplied potassium will recharge the adsorptive clays and organic matter so that a liberal supply is again available to the plants. An addition of 1 pound of muriate of potash per 100 square feet of soil surface is considered a liberal rate of application.

These elements are aided in their endeavors by the other essential elements—calcium, iron, magnesium, sulphur—and the other trace elements mentioned. *Calcium* exerts its influence both within the soil and also within the plant. It favors development of necessary bacteria; it counteracts the toxic effects of certain salt combinations in the soil; and it aids in the liberation of nitrogen, phosphorus, and potassium. Within the plant it functions in transportation of starch, in metabolic processes, and in formation of the cell wall. It may function in formation of nuclei and chloroplasts. *Magnesium* functions in the formation of seeds, nucleoproteins, cell division, chlorophyll, and transportation of phosphoric acid and facilitates the assimilation of sulphur and nitrogen. *Sulphur* is a constituent of plant proteins. *Iron* is mainly responsible for the formation of the green coloring matter of the leaves; it is beneficial to growth of fungi, and ferric oxide may promote the fixation of atmospheric nitrogen by soil bacteria.

Analyses and Costs of Fertilizers. Normally fertilizers are purchased for one or all of the essential elements of nitrogen, phosphorus, and potash. The percentages of these materials in different fertilizers vary. For example, according to the accepted analysis, ammonium sulphate contains 20 per cent nitrogen, and nitrate of soda 15 per cent nitrogen. Thus, in a ton of these materials there would be 400 and 300 pounds of nitrogen respectively. At the present price per ton of these materials, the gardener would pay about 8.7 cents per pound for nitrogen, using ammonium sulphate, and about 13.3 cents if he used nitrate of soda. In a commercial brand of fertilizer, such as 4-12-4, there is a total of 20 units (4N, $12P_2O_5$, $4K_2O$), or, in other

TABLE II

Carriers of Different Elements

Nitrogen

1. Organic

Cottonseed meal	7-3-2
Tankage	8-10-0
Soybean meal	6.5-6-1
Blood	14-0-0
Tobacco	3-0-10
Garbage tankage	3-0-0

2. Inorganic

Ammonium sulphate	20%
Nitrate of soda	15%
Calcium nitrate	15%
Urea	46%
Cyanamid	22%

Phosphorus

Superphosphate 16, 20, or 46% (20% most common)

Bone meal.... 3-22-0

Potassium

Potassium chloride	50%
Potassium sulphate	48%
Wood ashes (30 to 35% calcium)	4%

Combinations

1. Nitrogen-phosphorus
   Ammo-phos 11-48-0 or 16-20-0
2. Nitrogen-potassium
   Potassium nitrate 13-0-44

Complete Fertilizers

1. Common commercial grades
   2-10-10
   2-12-6
   4-12-4
   8-5-3
   10-6-4
2. Trade-name types

Nitrophoska	15-30-15
Bonro	12-6-4
Wedo	8-5-3
Fairway	6-6-4
Bloom Aid	5-10-3
Loma	4-12-4
Sacco	4-12-4
Vigoro	4-12-4

Boron

Boric acid (apply 4½–9 lb. per A. Larger quantities are toxic)

Calcium

Ground limestone

Calcium carbonate (air-slaked lime)

Calcium sulphate (gypsum, land plaster)

Iron

Ferrous sulphate

Ferric chloride

Ferric citrate

Ferric sulphate

Magnesium

Magnesium sulphate

Manganese

Manganese sulphate

Zinc

Zinc sulphate

Copper

Copper sulphate

words, 400 pounds of the essential elements combined in a ton of 4-12-4 fertilizer. The cost of this fertilizer is about 7.5 cents per pound, considered on the basis of the total units it contains.

The price per ton does not give a clear indication of the real value of the fertilizer. The gardener should figure its value on the amount of the essential element or elements he wishes to apply. It is apparent how uneconomical it would be to apply 4-12-4 if nitrogen alone were desired. The cost per pound of nitrogen would be over four times as much as nitrogen from ammonium sulphate. Yet this frequently happens when one fertilizer is purchased to satisfy all needs or when it is applied just because one has it on hand.

In view of the differing opinions regarding the potentialities and benefits derived from the use of bone meal, a consideration of phosphorus supply will be interesting. The cheapest sources of phosphorus are superphosphate and Ammo-phos. The latter is an especially useful fertilizer where both nitrogen and phosphorus are desired. Besides the favorable price the phosphorus in Ammo-phos is more readily available than it is in superphosphate or bone meal.

Bone meal is frequently employed as a source of phosphorus and to add a small amount of nitrogen. On the basis of cost alone, it is a rather uneconomical carrier. Figures show that cost of the nitrogen and phosphorus combined in Ammo-phos is 5.3 cents per pound, whereas the same elements combined in bone meal cost 6.6 cents per pound, or $1.30 per hundred more. The nitrogen in bone meal is readily available, but the phosphorus is very slowly available. Experimental tests have shown that applications of phosphorus with ammonium sulphate produced better results than when either fertilizer was used alone.

Soil Acidity

Much has been said about soil acidity and its action upon plant growth. Normally most ornamental plants grow best in slightly acid soils, although in some instances alkaline types are satisfactory. Acidity frequently results in soils that have been leached of the basic elements, leaving an excess of acid compounds. This makes an acid soil.

For the sake of safety, we would recommend slightly acid soils for the ornamental crops, because under such conditions the various elements needed for plant growth are available, and the slight degree of acidity is not sufficient to discourage the development of beneficial bacteria.

To secure such a reaction in the soil it is necessary to know the materials, the amounts to apply, and also the methods of determining the state of soil reaction. Without going into technicalities, it should be understood that the formidable term "pH" is a designation of a scale in which 7 is the neutral point and all numbers below show acidity, whereas those above indicate alkalinity. Thus pH 6.5 means slight acid; pH 5, quite acid; pH 7.5, alkaline; and pH 8, quite alkaline. The majority of ornamental crops are grouped in the range of 6 to 6.5. When the soil is 6 or below, only such plants as azaleas, gardenias, and hydrangeas *may* grow satisfactorily. When the soil reaction gets above 7.5, the great majority of ornamental crops will suffer.

The materials used to counteract acidity are forms of lime, usually ground limestone and sometimes dolomitic limestone. Occasionally calcium chloride and agricultural slag are also recommended for specific ailments. Since the most common material for correction is calcium carbonate or ground limestone, the recommendation for this follows: To raise the pH 5 to pH 6 on *sandy loams* would require about 2,500 pounds to the acre, or about 5 pounds to 100 square feet. To raise it from pH 6 to pH 6.5 would take an additional 500 pounds to the acre, or about 1 pound to the 100 square feet; and to bring it to the neutral point (pH 7) would take another 300 pounds. Using a heavier soil like a silt loam, it would take 3,440 pounds to the acre to change from 5 to 6; 1,000 pounds more to the acre to change from 6 to 6.5; and 600 pounds more to bring it to the neutral point. Clay loams require about 4,250 pounds of limestone to change from 5 to 6; 1,500 pounds more to change from 6 to 6.5; and 800 pounds more to bring the soil to the neutral point.

It should be understood that these amounts are not exact, since no two soils react the same to the additions of lime, but for general purposes they are accurate enough. To convert pounds to the acre you may figure roughly that 1,000 pounds to the acre is about 2 pounds to the 100 square feet.

If hydrated lime is used, two-thirds of the foregoing recommended amounts will suffice. However, its action is quick but not lasting, and care should be used in its application when combined with manures or other nitrogenous fertilizers, since damage may occur from rapid release of ammonia.

Alkaline soils may be made acid through the use of such materials as flowers of sulphur, aluminum sulphate, or iron sulphate. The sulphur is safer to use but does not produce the necessary reaction so quickly as aluminum sulphate or iron sulphate. In soils lacking in phosphorus, liberation of free aluminum may cause damage. Where phosphorus is abundant, such damage rarely occurs because of the combination of aluminum with phosphorus into an insoluble aluminum phosphate.

In an average medium-light silt loam it takes 4½ pounds of aluminum sulphate or iron sulphate to 100 square feet to bring the reaction down from pH 8 to pH 7, requiring approximately 2 weeks for the process. Nine pounds for the same area would be needed to bring it down to pH 6, and 13½ pounds to bring it to 5.5.

If flowers of sulphur were used, 2 pounds to 100 square feet would bring the reaction from pH 8 to pH 7 in 6 weeks. To get it down to pH 6.5, 3 pounds to the 100 square feet would be required, and the time needed would be about 8 or 9 weeks. To get it down to pH 6, 4 pounds would be needed for the same length of time.

Once these limits are reached, the soil reaction would remain constant, were it not for the leaching and the applications of alkaline water which might necessitate additions of acidifying materials at regular intervals. These cannot be predicted, but regular tests for acidity will bring out the needs.

Fertilizers Reputed to Have Neutralizing Power

Bone meal has a slight effect in reducing acidity.

Basic slag has about one-fifth the effect that ground limestone has.

Superphosphate contains no free lime and has little, if any, neutralizing power.

Hardwood ashes are high in lime content and in some instances neutralize acidity to the extent of 70 per cent of that of ground limestone.

Gypsum has no value in neutralizing soil acidity.

Cyanamid is a nitrogenous fertilizer with a very high neutralizing power—almost equal to that of limestone.

Manure has been said to be useful in reducing acidity. Actually the calcium content is useful in promoting growth but is not effective in neutralizing soil acidity.

Ammonium sulphate is said to be effective in acidifying soils. This would be true in ground beds where little leaching takes place. In greenhouse benches and particularly where heavy watering is practiced and the fertilizer used at infrequent intervals, there is little danger from its acidifying effect, although in some soils such may be the effect. In outdoor soils it has a definite acidifying effect.

Cottonseed meal and *tankage* have a very definite acidifying influence.

Most of the complete inorganic fertilizers have little or no effect upon the soil reaction, although nonacid combinations are now on the market.

Chapter III

NUTRIENT DEFICIENCY SYMPTOMS OF SOME HORTICULTURAL CROPS

THE constant depletion of our soils and lack of thorough understanding of the use of fertilizers result frequently in the lack of certain elements of plant growth. Such deficiencies are mistaken for disease attacks, insect injury, and various other troubles. If the symptoms of such deficiencies could be recognized in the early stages of growth, and corrective measures taken, many malnutritional troubles could be avoided by the gardener or the commercial grower. To that end the author with two assistants, E. W. McElwee and Arnold Wagner, conducted a series of tests at the Ohio Agricultural Experiment Station at Columbus beginning in 1930 and continuing until 1939. The results of this work are herewith presented.

SYMPTOMS OF NUTRIENT DEFICIENCY

1. *Begonia semperflorens*

Minus Nitrogen

Growth is stunted, and the foliage is brick red in color. There are very few flowers.

Minus Phosphorus

No side breaks develop, and growth is stunted. The color of the plant is normal.

Minus Potassium

The growth is almost normal. However, there is a very definite burning of the margins of leaves, and they turn brown and eventually drop.

Minus Boron

After growing 6 months in the same culture pots, the terminal bud and leaves exhibit a rosette condition with puckering of the tip leaves. In 2 weeks this is followed by a necrosis of the terminal bud and leaves which makes further terminal elongation and growth impossible.

Minus Calcium

The plants soon become stunted in growth. The leaves become a dull light green with reddish margins, are very small, and have short petioles. Later the terminal bud and tip leaves die. Those plants which were grown in complete solution for a period and then transferred to minus calcium culture began wilting after 2 weeks and remained wilted until the plants died entirely. Upon examination of the root system, it was found that it was brown and decomposed.

Minus Iron

After 1 month a chlorosis develops on the terminal leaves of each shoot. The veins remain normally green while the areas between the veins become yellow.

Minus Magnesium

Deficiency of magnesium is very marked in the case of begonia. The plant soon stops growth, and a stunted condition results. The leaves are extremely small, and the petioles exceedingly short. A chlorosis develops on the lower and middle leaves between the veins, leaving the veins a normal green. Soon after this a puckering of the leaf is noticed; and not many days later, occurring within a 24-hour period, there is a severe necrosis of the chlorotic leaves. These areas enlarge and dry to a crisp very soon thereafter. Some of these necrotic areas are darker colored than others. There is some leaf abscission.

In magnesium deficiency the lower part of the plant is affected first, and the symptoms progress upward. Therefore, the terminal bud is the last part of the plant to become affected, as the deficiency becomes more and more acute. If complete solution is added before the deficiency progresses too far, the plant will recover quite rapidly. Of course, the necrotized leaves will never recover, but new growth from the axils of the stem masks their bad appearance.

Minus Manganese

Manganese-deficient begonias do not become so severely stunted as magnesium-deficient ones. However, there is a chlorosis of the leaves occurring between the veins. The chlorotic areas later become necrotic, but these necrotic areas differ from those in magnesium deficiency in that they remain translucent and watery in appearance, not drying so rapidly. The remaining leaves are dull grayish green in appearance. Manganese deficiency appears first on the terminal portions of the plant. Necrosis due to manganese deficiency is never so severe as that due to magnesium deficiency.

Minus Sulphur

The first symptoms of sulphur deficiency on the begonia is a slower rate of growth. The plants are usually about one-half the size of plants grown on complete solution. The leaves are a dull, gray, yellow-green.

2. *Calceolaria rugosa*

Minus Nitrogen

The plants are dwarfed with small flower clusters. Old leaves are almost white in color with light brown, dead margins. The young leaves are very pale yellowish green.

Minus Phosphorus

Plants are small and of an unusually dark green color and show no indication of a flower cluster. The old leaves have some yellowing around the margins.

Minus Potassium

The plants are only slightly stunted, but the flower cluster is poorly developed, and the flowers faded in color. The older leaves are brittle, crinkled between the veins, and of a normal green color except for the affected areas. The margins of the older leaves and the area around the petiole die and dry to a dark brown to black color, with the centers of leaves showing large spots with necrotic centers. The young leaves are light to yellowish green in color.

Minus Calcium

The first noticeable effect is a reduced rate of growth followed by a wilting and yellowing of the plant. In later stages the terminal bud dies. The roots are brown and decomposed. In the last stages the entire plant dies.

Minus Iron

The terminal leaves exhibit a chlorosis between the veins.

Minus Magnesium

Following a reduced rate of growth, chlorosis develops between the veins of the leaves on the lower part of the plant and progresses upward. Later, small reddish-brown necrotic spots cover the leaves, and the latter have a tendency to turn downward at the tip and margins. The plant becomes very stunted.

Minus Manganese

The first symptom of manganese deficiency in this plant is a very pronounced chlorosis of the terminal leaves extending from the margins back to the midrib between the veins, the veins remaining green. This gives a streaked appearance to the leaf. The plants never become stunted in appearance until small necrotic spots develop in the chlorotic areas of the leaves.

Minus Sulphur

A greatly reduced rate of growth and chlorosis of leaves are the two symptoms noted on this deficiency.

3. *Carnation (Dianthus caryophyllus)*

Minus Nitrogen

The leaves are short and do not exhibit their usual healthy bloom. Internodes, as well as the entire stem, are short. Flowers are small.

Minus Phosphorus and Potassium

Difficult to tell apart, but lack of either produces limber stems. Lower foliage turns brown and dies. There is a greater susceptibility to disease.

Minus Iron and Manganese

Deficiencies are difficult to observe.

Minus Calcium

Weak stems may occur.

4. *Chrysanthemum hortorum*

Minus Nitrogen

Yellow foliage (general over the entire plant), small leaves, woody stems, and short internodes characterize this deficiency. There is no drop of foliage.

Minus Phosphorus

Gray-green foliage, which is darker near the petiole and pale green near the edges, drops gradually from the base up. The growth is stunted throughout.

Minus Potassium

Small leaves, gray-green foliage, slight mottling are typical of this deficiency. There is a very characteristic browning of the edges of the leaves, eventually spreading further back.

Minus Calcium

With this deficiency, nearly all the root hairs die within 2 or 3 weeks' time. The roots are short and thick, dirty brown in color, and appear decomposed. The top ceases to grow, and the plant remains stunted, finally dying after several weeks. Leaves are small and have short petioles. Terminal buds and leaves die. Some chlorosis of leaves may occur. After plants have been severely stunted, they recover very slowly when grown on a complete solution. Stems are very stiff. The plants do not produce flowers.

Minus Iron (Fig. 2)

In chrysanthemums minus iron there is a very severe chlorosis developing by degrees from a mild chlorosis, first becoming evident on the young leaves at the tip of the plant and later progressing downward. The first

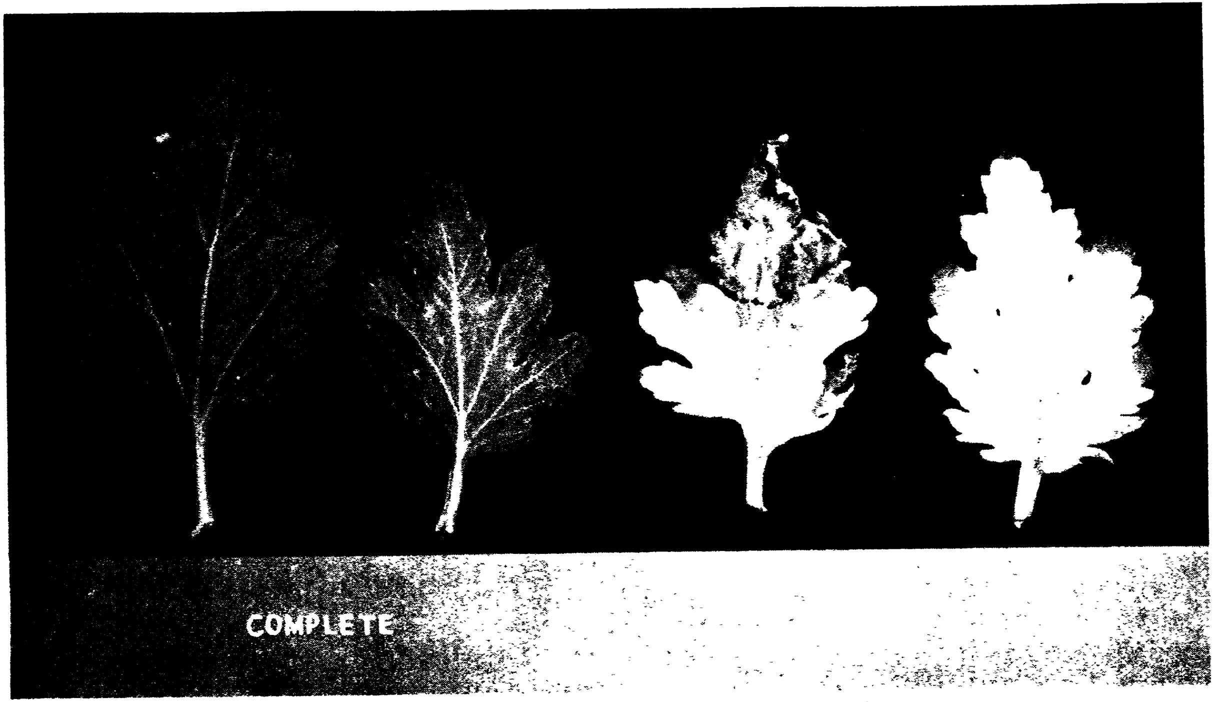

Fig. 2.—Chlorosis in chrysanthemum caused by lack of iron.

casual glance gives the impression of dark green veins with chlorosis occurring between the veins. However, upon closer examination, it is seen that the veins are yellow with narrow strips of green tissue adjacent on each side. This accounts for the general impression of dark green veins. With a severe deficiency of iron the leaves turn completely white or cream in color. Soon after this stage is reached a severe burning or necrosis of the chlorotic leaves develops. The burned area is small at first, increasing in size until a large part of the leaf is desiccated. This burning may begin anywhere on the leaf, but it usually occurs on the tip or margins, increasing inward.

If severely deficient plants are given complete solution, all new growth will be normal, but some of the more chlorotic leaves never regain their green color. The roots on plants that lack iron are relatively short and have many short branches. They are intense reddish brown in color and appear partly decomposed. Blooming is delayed.

Minus Magnesium

The effect of deficiency in magnesium on the chrysanthemum is marked by greatly decreased rate of growth. A chlorosis develops between the veins, which themselves are left a normal green. This appears first on the lower and mid-portion of the plant, later progressing upward. The leaves curl upward at the tips and margins, giving a dishlike appearance. Leaves are very small, and the petioles short. In severe cases of deficiency, the leaf petiole shrivels, causing the leaf to hang down against the stalk. A purple coloration develops on the leaves in blotches, after the plant has become stunted. If a complete solution is added before the deficiency becomes acute, almost full recovery of the plant can be expected. The blooming period is delayed by 2 weeks, and the blooms are smaller, some of them being aborted. Roots are few in number, with few lateral branches. They are slimy in appearance.

Minus Manganese

Manganese deficiency also stunts the chrysanthemum but not so severely as lack of magnesium. There is an orange-yellow chlorosis between the veins of the leaves, starting on the tip of the plant, leaving the veins normal green. The leaf margins and tip curl under, until the leaf is almost folded double. There is a slight purple coloration of the leaf which was noticed more prominently in the case of magnesium deficiency. When complete solution is added, recovery is rapid. Blooming is delayed.

Minus Sulphur

The lack of sulphur results in a decided reduction in the height of the plant. The younger leaves of the plant, as well as those of medium age, are lighter green than those of normal plants. Chlorosis due to lack of sulphur is very characteristic in that the veins are lighter in color than the areas between the veins. In the later stages there is a characteristic dying of the leaf veins just at the base of the leaf blade. This dead area is purplish brown in color. It remains soft and moist, not drying readily. It proceeds along the veins until the leaf tips are reached. Along with this development, the remainder of the leaf dies. Plants will recover if they are given complete solution before this necrosis at the base of the leaf blade becomes evident. Blooming is delayed. Roots on plants that lack sulphur are abundant and much branched.

5. *Cineraria cruenta*

Minus Nitrogen

The plants are stunted in growth soon after being deprived of nitrogen. The flower buds are small and poorly developed. All the leaves are rusty yellow in color and remain attached to the plant for a long time after drying.

Minus Phosphorus

The plants are partially stunted, with small leaves of an abnormally dark green color. The older leaves begin to turn yellow and die but usually drop before becoming completely yellow.

Minus Potassium

The plants are slightly stunted in growth. The older leaves are mottled with whitish-yellow markings between the veins and along the margins of the leaf. The margins later turn brown.

Minus Calcium

These plants are stunted very early in their growth, become necrotized, and finally die completely. Roots are brown and decomposed. Plants that had been started on complete solution for 2 months and then transferred to minus calcium started wilting after 1 week and finally died. This was due primarily to the root injury caused by a lack of calcium.

Minus Iron

There is a chlorosis of the leaves, normal green veins, and yellow between the veins. The plants are stunted.

Minus Magnesium

These plants are severely dwarfed. A chlorosis appears between the veins. Necrotic areas appear on the margins and between the veins. These increase in size until the entire leaf is dead. The leaves are extremely crinkled, the leaf margins curling upward, giving a revolute appearance. Growth is very stunted.

Minus Manganese

The plants grown on minus manganese exhibited poor growth the entire period of the experiment. There is a slight chlorosis followed by the appearance of necrotic areas on the leaf, finally leading to death.

Minus Sulphur

A light foliage and poor growth were the only symptoms noted.

6. *Fuchsia hybrida*

Minus Nitrogen

The plants are very stunted and produce few side shoots. All the leaves gradually turn yellowish green, the older ones finally changing to an orange color and dropping before completely dying. The plants flower prematurely, with malformed flowers.

Minus Phosphorus

The plants are very stunted in growth. The older leaves are of an unusually dark green color, and the young leaves of a bronze-purple color, crinkled and rosetted.

Minus Potassium

The plants are only partially stunted. The older leaves are dark green in color and show some browning in spots between the veins and along the margin of the leaf. The young leaves are slightly yellowish green in color and rolled inward along the margins.

7. *Gardenia veitchi*

Minus Nitrogen

There are stunting of growth and general yellowing of the foliage over the entire plant.

Minus Phosphorus

There is a general stunting, with darker foliage than usual.

Minus Potassium

Marginal dying of the leaves is characteristic.

Minus Boron

After 6 months, chlorosis is evident on the tip leaves. Soon after this these areas become necrotic, and the terminal growth ceases. The leaves become very crinkled and deformed.

Minus Calcium

The first evidence of the deficiency is very slow growth. A chlorosis develops on the leaves. Later the terminal bud dies, and necrotic areas appear on the leaf margins and tip at the top of the plant. This causes a crinkling of the terminal leaves. Root injury is apparent after 2 weeks, and in a short time the entire plant dies. After root injury has taken place, recovery following the addition of a complete nutrient solution is exceedingly slow.

Minus Iron

In minus iron there is a very severe chlorosis, first becoming evident on the young leaves at the tip of the plant and later progressing downward. In the early stages the veins remain a normal green; but as the deficiency becomes acute, the leaves turn completely white or cream. Soon after this stage is reached, a severe burning of the chlorotic leaves develops. The burned area is small at first, increasing in size until a large part of the leaf is desiccated. This burning may begin anywhere on the leaf, but it most frequently occurs on the tip or margins, spreading inward. Plants become very stunted. If severely chlorotic plants are given complete solution, all new growth will be normal, but some of the older and more chlorotic leaves will never regain their green color.

Minus Magnesium

The plant becomes very stunted early in the experiment and dies completely after 3 or 4 months. The leaves absciss easily, and the plant becomes defoliated gradually, defoliation progressing from the bottom to the top. Necrotic areas appear on the margin of the leaves and enlarge inward. After this condition has been reached, recovery is exceedingly slow when complete solution is added regularly. The roots are very poorly developed and slimy in appearance.

Minus Manganese (Fig. 3)

Manganese deficiency stunts gardenias but not so severely as does magnesium deficiency. The first evidence is a chlorosis of the top leaves of each shoot, the yellowing coming between the veins. This chlorosis later progresses downward on the plant. Even the most minute veins remain green, thus giving a very fine network appearance over the leaf. Shortly after the chlorosis has appeared there is a severe necrosis of these yellowed areas followed by abscission of the youngest of these leaves. This necrosis frequently takes place on the leaf tip. It is very characteristic in that it is reddish brown in color, whereas that due to minus iron is a true brown. Also, the necrotic spots are much smaller in the case of manganese deficiency. The necrotized leaves become crinkled and deformed. In some cases, on smaller younger leaves particularly, the entire leaf becomes necrotized and abscisses. When complete solution is added before the deficiency becomes acute, partial recovery will take place. Gardenia flowers in this deficiency have open centers.

Minus Sulphur

The foliage is of a lighter green, and the amount of growth is about one-half as compared with that of plants given complete solution.

8. *Geranium (Pelargonium hortorum)*

Minus Nitrogen

Plants are extremely stunted in growth, with only a central stem and no flower clusters. The young leaves are light green in color with a definite reddish-bronze ring around the center. The older leaves turn a brilliant red except for a yellowish-red area around the petiole, dry up, and remain attached to the plant for some time.

Minus Phosphorus

The plants are stunted almost as much as those in the treatment without nitrogen but show a well-developed flower cluster of good color. The young leaves are dark green in color and show a distinct chocolate-brown ring around the center. The older leaves turn dull, dark red, progressing from the margin toward the petiole; dry; and drop from the plant early.

Minus Potassium

The plants are only slightly smaller than those in the complete treatment and produce several side branches and flower clusters. The young leaves are a pale, yellowish-green color with dark green veins. The older leaves are grayish yellow between the veins and along the margins, with some yellow and brown spotting between the veins; and show a distinct, rusty-brown ring around the center. There are some yellowing and brown spotting between the veins of the old leaves.

Minus Calcium (Fig. 4)

The plant becomes very stunted and fails to put forth any new growth after being placed on minus calcium. Roots soon become brown and decomposed in appearance.

Minus Iron

A general chlorosis between the veins is noted on the tip leaves of the plants.

Minus Magnesium

A chlorosis on the lower part of the plant is the first evidence of magnesium deficiency of the geranium. This chlorosis begins on the margins and progresses inward between the margins until a large part of the leaf is yellow. The only green portion remaining is a fan-shaped area at the base of the leaf blade extending out along the palmate veins for a short distance. This chlorosis progresses upward on the plant as the deficiency becomes more acute. The leaves of middle age and younger exhibit a puckering effect. The plants are very stunted, leaf petioles are short, and roots are very few in number.

Minus Manganese

A chlorosis appears on the tip of the plant. The areas between the veins are yellowed while even the most minute veins retain their normal green color. This gives a very finely netted appearance of the leaf. Although growth is somewhat poorer than with the complete solution, the plants do bloom, but the flower color is poor and faded.

Minus Sulphur

Lighter green foliage and decreased growth were the only symptoms noted.

9. *Hydrangea hortensis*

Minus Nitrogen

Light foliage, light-colored veins, short growth, and small leaves characterize this deficiency.

Minus Phosphorus

The plant fails to develop flowering buds.

Minus Potassium

The plant fails to develop flowering buds, and this failure is accompanied by browning of edges of leaves.

Minus Calcium

Hydrangeas grown on minus calcium die within 4 weeks. The terminal growth is killed first. Roots are brown and decomposed.

Minus Iron

Iron chlorosis is exhibited, the intervenal areas becoming yellow while the veins remain a normal green. This appears on the terminal leaves of the plant.

Minus Magnesium

Magnesium deficiency is particularly destructive to the hydrangea. There is a chlorosis of the leaf (dark veins, yellow between) followed by death of the entire plant after being on the deficiency for 1 month.

Minus Manganese

After a period of 1 month the usual symptoms for manganese deficiency gradually become apparent. There is a chlorosis of the terminal leaves between the veins.

Minus Sulphur

Hydrangeas on minus sulphur produce about one-half the growth of the complete nutrient plants. The leaves are a lighter green. In the later stages a bad infection of mildew caused the plants to become completely defoliated. Since the minus-sulphur plants were the only group to be thus affected, and since sulphur dust is used to combat mildew, it is suggested that there may be some correlation between sulphur deficiency of a plant and its susceptibility to mildew.

10. *Poinsettia (Euphorbia pulcherrima)*

Minus Nitrogen

The plants show a uniform yellowing of all leaves, beginning with the bottom and progressing to the top. The older leaves turn pale yellow and drop.

Minus Phosphorus

The plants make very little growth. The older leaves begin yellowing from the margins toward the center of the leaf and drop before becoming completely yellow. All leaves drop in succession until only the topmost leaves remain; these are abnormally dark green in color.

Minus Potassium

The plants are only partially stunted in growth. The older leaves begin to turn yellow along the margins and finally turn completely yellow except for the veins, which remain dark green in color. Browning along the margin begins after the leaves become completely yellow, the leaves remaining attached to the plant for some time after dying. All the leaves are finally affected except the young bud leaves at the tip. These remain dark green. The plants produce several side branches which develop normally for a short time and then begin to turn yellow, and later brown, along the margins.

Minus Boron

The first injury occurs about 3 months after plants are placed in this deficiency. The buds cease to grow and have a somewhat drawn, stunted appearance. This automatic topping causes the side buds near the tip to develop. The terminal leaves thicken and have a tendency to roll in a half circle from the tip toward the base. On some leaves the midrib on the under side of the leaf cracks. The bracts develop slowly and abnormally.

Minus Calcium

The tip leaves become abnormally dark green with a reddish tint and exhibit wilting. Stems are very stiff. The terminal bud dies, and complete defoliation occurs. Root injury is severe.

Minus Magnesium

Magnesium deficiency results in a severe stunting of the plant. There is the characteristic chlorosis, dark veins with the yellowing occurring on the lower part of the plant. This is accompanied by a puckering of the leaf. Necrotic spots occur on the margins and between the veins. These areas increase in size until the entire leaf is desiccated. Leaf margins generally curl under. The bracts are extremely small and imperfect.

Minus Manganese

On the tip of the plant a chlorosis develops which is not so severe as magnesium chlorosis, giving more or less of a mottled appearance to the leaf. Manganese-deficient poinsettias are about one-half the size of those grown in complete solution. Bracts are also smaller.

Minus Sulphur

The foliage color is a light dull green. Yellowing, followed by necrosis of the tissue at the base of the leaf blade, is evident in the later stages of deficiency. This necrosis extends along the midrib. The sulphur-deficient plants are much smaller than those grown in complete solutions.

11. *Primula obconica*

Minus Nitrogen

The plants are very stunted in growth, with all the leaves small and light yellowish green in color, and show no indication of flowering.

Minus Phosphorus

The leaves are unusually dark green in color, deeply crimped, and yellow along the margins. No flower clusters develop.

Minus Potassium

The young leaves are of normal color, but the older ones are yellow in spots and along the margins. The veins of the affected leaves remain green until the leaf dies. Flower clusters are faded.

Minus Calcium

These plants die after 1 month's treatment. Root injury is apparent. When plants that had been started in complete solution were transferred to minus calcium, wilting took place within a week, and after 1 month the plants were completely dead.

Minus Iron

The characteristic chlorosis develops. The veins remain normal green while the areas between become chlorotic.

Minus Magnesium

Chlorosis develops between the veins, the veins remaining normal green. Prior to this, however, a chlorotic band forms around the margin of the leaf. Following the chlorosis, a very puckered condition of the leaf develops. In the later stages, a severe necrosis appears between the veins and on the margins. The plants are stunted severely. The plants flower, but the clusters are very poor in size, color, and quality.

Minus Manganese

There is a reduced rate of growth as well as the typical manganese chlorosis. The chlorosis comes between the veins while the most minute of the veins remain green, giving a very netted appearance to the leaf.

Minus Sulphur

This deficiency is characterized by chlorosis, the veins being lighter than the rest of the leaf. Growth is reduced.

12. *Rosa hybrida*

Minus Nitrogen

The foliage turns yellow and remains on the plant. Shortening of growth, failure to develop buds properly, and small flowers of light color are also characteristic.

Minus Phosphorus

The older foliage drops without turning yellow. This should not be confused with foliage drop due to overwatering, for the latter is accompanied by yellowing first. Weakness of stems, slow development of buds, poor production due to smaller root systems are also characteristic.

Minus Potassium

Marginal browning of foliage, occasional purpling of leaves, poor color, and weak stems typify this deficiency.

Minus Calcium

Roots die in a short time. Concurrently with this, the terminal bud dies, and the plant becomes entirely defoliated.

Minus Iron

The first symptom is a light chlorosis developing on

Fig. 5.—Symptoms of magnesium deficiency in the rose.

the tip leaves of the plant. This chlorosis increases gradually until it is very marked. The veins remain dark green while the intervenal areas become chlorotic. As the deficiency becomes more acute, the chlorosis progresses downward on the plant. Small necrotic areas appear on some of the more chlorotic leaves. The plants lacking iron bloom, but the flowers are very light colored in comparison with the flowers of the complete plant. It is noted with interest that the roots of minus-iron plants are nearly white in color, there being only a slight browning of the cortex of the older roots which is probably due to natural maturation of the tissues.

Minus Magnesium (Fig. 5)

The plants are very stunted in growth and produce few breaks. The first stage is a chlorosis appearing on the lower part of the plant with dark veins, yellow between. After 2 months of treatment, dry necrotic areas, small at first and intervenal, appear. These form a row of necrotic spots halfway between the veins and the midrib, following the outline of the margin of the leaf and giving an oval-shaped ring of dead tissue. These spots enlarge until most of the leaf is dead. Flowers are smaller and of poor color. Roots are thickened and have few laterals.

Minus Manganese

A chlorosis appears between the veins. Manganese chlorosis is very difficult to distinguish from iron chlorosis; but as a general rule, in the case of manganese chlorosis, even the most minute veins remain green while the areas between are yellowed. This gives a very netted or checkered appearance to the leaf. Manganese chlorosis appears on the top of the plant.

13. *Snapdragon (Antirrhinum majus)*

Minus Nitrogen

The plants are very stunted in growth and produce few shoots. The young leaves are light green in color with some yellowing along the margins and between the veins. The old leaves are rusty yellow to rusty yellowish green in color. After dying, the old leaves remain a rusty color and cling to the plant for some time.

Minus Phosphorus

The growth is stunted, and the young leaves become unusually dark green. The old leaves are bronzy dark green and show a definite purple cast beneath, later shriveling and dying.

Minus Potassium

The plants are only slightly stunted in growth. The young leaves are yellowish green in color with dark green veins and a reddish tinge along the margin. The older leaves turn purplish green in color on the upper surface but not purplish beneath like those in the treatment without phosphorus. These leaves begin to die first along the margin and in spots over the entire leaf.

Minus Calcium

Plants are killed almost immediately in the young seedling stage after being placed on calcium deficiency. Plants that were first grown on complete nutrient solutions for a while and then transferred to calcium deficiency began to wilt after 1 week. The wilted condition became more severe until the entire plant became brown and dried. Root injury was apparent.

Minus Iron

A chlorosis develops between the veins of the terminal leaves of the plant. Plants are stunted. Flower color is much lighter than normal.

Minus Magnesium

The first evidence of magnesium deficiency is a chlorosis between the veins of the leaves on the lower part of the plant. Later, white necrotic areas develop on the leaves between the veins. This gives the leaf a crinkled effect. The tips of the leaves hook down, and the margins curl upward. The growth of the plant becomes very stunted. The petioles and leaf blades shrivel and dry, causing the leaves to drop along the axis of the plant. There are one or two flowers per spike, the color fading almost to a white. After some time the plant dies entirely. If complete solution is added before the deficiency becomes acute, recovery will take place in a short time. It is to be understood, however, that any necrotized areas that have appeared previous to the time of application of complete solution will never recover, but all the new growth will be normal.

Minus Manganese

A chlorosis develops between the veins on the tip leaves of the plant, arranged in such a manner as to give a somewhat mottled effect. In later stages the small leaves just emerging from the terminal bud become very chlorotic. Later small necrotic spots appear on the upper leaves, the margins curl under, and the tips turn down.

Minus Sulphur

The typical sulphur chlorosis develops, the veins being lighter than the rest of the leaf. These symptoms are found on the terminal leaves of the plant in the early stages and later progress downward. The plant blooms, but it is somewhat smaller.

14. *Sweet Pea (Lathyrus odoratus)*

Minus Nitrogen

The plants are very stunted in growth, and all the leaves are very light yellow, almost white, in color. The old leaves dry to a grayish-white, papery color and remain on the plant some time before dropping.

Minus Potassium

The plants are stunted in growth, and the older leaves show a progressive yellowing from the margins to the center of the leaf. The veins of the yellowing leaves remain green until the entire leaf has turned yellow. The yellowing progresses upward until only the young leaves at the tip remain green. The dead leaves drop from the plant early.

Minus Boron

These plants did not grow over 6 inches high. The terminal bud is killed, and the leaves of the entire plant turn yellow. Root injury is severe.

Minus Calcium

The earliest symptom is a dying back of the root tips. The roots are very short and stunted. This is followed shortly by death of the terminal bud and yellowing and necrosis of the leaves. In the last stage the plant is entirely necrotized, the leaves being almost white in color.

Minus Magnesium

The first symptom is a decreased rate of growth. Chlorosis soon appears between the veins. Not long after this, the leaf exhibits large white necrotic areas between the veins. The deficiency symptoms begin on the lower part of the plant but quickly progress to the top of the plant. No puckering of the leaf is noticed. Needless to say, the plants are very stunted, and the root system is very small.

Minus Manganese

A chlorosis appears on the terminal leaves between the veins. Puckering of the leaf is evident, and later necrotic spots appear. These spots resemble raised welts about the size of a pinhead and are distributed evenly over the leaf.

15. *Tomato*

The Maryland Agricultural Experiment Station reports the following symptoms of nutrient deficiency:

Minus Nitrogen

The entire plant turns yellow in about 6 to 8 days. Lower leaves dry up slowly and drop off. Leaves and stems are abnormally small. Veins turn pink in color. Roots are unbranched and white.

Minus Phosphorus

The symptoms appear in 7 to 10 days. Plants become dark blue, green, or purplish in color. Lower leaves gradually blacken. Stem is slender, stunted, and covered with deep blue spots. Roots are long, with few lateral branches, and brown in color.

Minus Potassium

The leaves near the margin show yellowish to brown spots, which spread gradually until they turn yellow and die. Growth is retarded. Main stem is slender and etched. Margins of leaves turn under, and the leaves become pimpled between veins. Roots turn pale yellow.

Minus Magnesium

Chlorosis of leaves appears. Leaves turn light green and later yellow, beginning at the margin and slowly spreading inward between the veins until the whole leaf is affected. Leaves tend to cup upward. Veins are unaffected. Stems are slender. Petiole etches, and leaves drop. Roots are long but unbranched.

Minus Calcium

Plants become weak and flabby. Terminal bud dies. Stem near terminal becomes spotted with dead areas. Upper leaves first turn darker green than normal, then yellow at edges, dry, and drop off. Lower leaves remain normal. New leaves die quickly. Roots are short, dark brown, and partially decomposed.

Minus Sulphur

Symptoms appear in 2 weeks. Leaves are thick and firm. Entire plant is pale green, and the under sides of veins are purple. Stem is stiff and woody. Roots are white with many branches.

Minus Boron

Cotyledons and leaves turn purple. Stems are stunted. Terminal shoots curl inward, yellow, and die. Petioles and midribs become brittle. Roots are small, yellow to brown. Fruits are covered with dark areas.

16. *Apples*

The New Jersey Agricultural Experiment Station reports the following symptoms of nutrient deficiencies:

Minus Nitrogen

Leaves are yellowish green. New leaves are small.

Red color is present in veins and petioles. Leaves assume an upright position, and petioles form narrow angles with the stem. Current growth of twigs and stems is short and slender. Roots are slender with yellowing cortex on new growth.

Minus Phosphorus

Foliage is abnormally dark green. Old leaves appear mottled and lighter than young leaves. Stems and leaves are highly colored purplish red, especially near the ends of twigs. Leaves have a leathery texture and form abnormally sharp angles with the stems.

Minus Potassium

Twigs and stems are slender. Leaves are small. Leaf scorch appears first as a dull purplish discoloration about the margins. The discolored areas change from purple to dark brown without an intermediate white stage.

Minus Calcium

Stem length restricted. Twigs die back from the tips. Roots are short and stubby with brown tips. Discoloration is prominent along the leaf margins extending about ¼ inch toward the midrib. Veins become tinged with purple while the rest of the tissue changes to dark brown.

Minus Magnesium

New leaves are thin and soft. A slight mottling of the leaf develops quickly, followed by blotching between veins and along the margins. This appears on old leaves first. Drop of leaves affected occurs in a few days after the appearance of blotches. The cortex of roots dies quickly and turns brown. The general leaf appearance is of graying-green spotting or mottling, later fading to a cream-white and then changing to brown.

Chlorosis

Deficiencies of iron, manganese, magnesium, and sulphur cause chlorosis (lack of green coloring matter) of the foliage. This is readily understood when we realize that these elements are either the component parts of chlorophyll or else have a catalytic function in chlorophyll formation and maintenance. It should be further understood that chlorosis may develop from other causes; so that before a deficiency of any particular element is blamed for the trouble, other factors of culture should be looked into. For example, over-watering, poor root systems, disease attacks, low temperature, lack of light, nicotine fumigation in the greenhouse, improper pH of the soil, strong insecticides and fungicides may all or in part be responsible.

The reasons for the various deficiencies are several. The soil may have insufficient quantities of the needed elements, or else these elements may be in unavailable form. The soil reaction may be too alkaline and thus reduce the availability of iron, manganese, nitrogen, phosphorus, potassium, or boron. Or it may be too acid, resulting in lack of availability. Another factor is the possible antagonism between elements. This is exemplified by the action of calcium and potassium. High calcium may interfere with the absorption of potassium, and vice versa. The same is true for calcium and manganese, nitrogen and potassium. iron and manganese, magnesium and potassium.

A Key to Nutrient Deficiency Symptoms

A. *Effects general on whole plant or localized on older, lower leaves.*
   1. *Effects usually general on whole plant* although often manifested by yellowing and dying of older leaves.
      a. *Foliage light green.* Growth stunted, stalks slender, and few new breaks. Leaves small, lower ones lighter yellow than upper. Yellowing followed by a drying to a light brown color, usually little dropping. *Minus Nitrogen.*
      b. *Foliage dark green.* Delayed growth. Lower leaves sometimes yellow between veins but more often show a tendency to develop a purplish coloration, particularly on the petiole. Leaves drop early. *Minus Phosphorus.*
   2. *Effects usually local on older, lower leaves.*
      a. *Lower leaves mottled, usually with necrotic areas near tip and margins.* Yellowing begins at margin and continues toward center. Margins later become brown and curve under, and older leaves drop. *Minus Potassium.*
      b. *Lower leaves chlorotic and usually show necrosis in late stages.* Chlorosis appears between the veins, veins remaining normal green. Leaf margins may curl upward or downward or develop a puckering effect. The necrosis develops between the veins

very suddenly, usually within 24 hours. *Minus Magnesium.*

B. *Effects localized on new leaves.*

1. *Terminal bud remaining alive.*

a. *Leaves chlorotic between the veins; veins remain green.*

(1) *Necrotic spots usually absent.* Extreme cases show necrosis of margins and tip of leaf which sometimes extends inward, developing large areas. Only the larger veins remain green. *Minus Iron.*

(Certain cultural factors such as high pH, over-watering, cold temperature, and nematodes on roots may cause identical symptoms. However, this is still probably a case of iron deficiency in the plant due to unavailability of iron caused by these factors.)

(2) *Necrotic spots usually present* and scattered over the leaf surface. Checkered or finely netted effect produced by even the smallest veins remaining green. Poor bloom, both size and color. *Minus Manganese.*

(3) *Leaves light green, veins lighter than adjoining intervenal areas.* Some necrotic spots may appear. Little or no drying of older leaves. *Minus Sulphur.*

2. *Terminal bud usually dies.*

a. *Breakdown at tip and margin of young leaves.* Young leaves often definitely hooked at tip. Death of roots actually precedes all the foregoing symptoms. *Minus Calcium.*

b. *Breakdown at base of young leaves.* Stems and petioles are brittle. Death of roots, particularly the meristematic tips, ensues. *Minus Boron.*

Chapter IV

FERTILIZATION OF CROPS IN SOIL AND THE EFFECT OF OVERDOSES

SO MUCH misinformation is found in current advice concerning the methods of fertilization that the average person is at a loss to pick out the wheat from the chaff. Personal experiences based on specific climatic and soil conditions find their way into print and are indiscriminately applied, irrespective of conditions. Empirical practices handed down from generation to generation are held sacred, and new ideas are scoffed at. To eliminate such confusion, the fertilizer requirements of ornamental crops outdoors and in the greenhouse are presented here in brief form.

ANNUALS AND HERBACEOUS PERENNIALS OTHER THAN BULBOUS OR TUBEROUS-ROOTED PLANTS

Thorough preparation of the soil is essential. Incorporation with the soil, at its initial preparation, of 2 inches of well-decayed manure or other organic matter and 10 pounds of superphosphate per 100 square feet is advisable. With perennials the winter mulch of manure, leaves, or peat should be worked into the soil in the spring. Further applications:

Annuals: Use 4-12-4, 2 to 3 pounds per 100 square feet in July and again in August if needed.

Perennials: Use superphosphate, 3 to 4 pounds per 100 square feet each spring followed by 4-12-4, 3 pounds per 100 square feet in May and again in July if needed.

BULBOUS AND TUBEROUS-ROOTED PLANTS

Dahlias. Light loam soils are preferred. Superphosphate, 5 pounds per 100 square feet, should be used before planting. Apply 2-10-10, 2 to 3 ounces per plant when tops are 1 foot high. Nitrogenous fertilizers should be added if a deficiency of nitrogen is shown by yellowing of the foliage. Use ammonium sulphate, 1 ounce to 2 gallons of water to 12 square feet.

Gladiolus. Slightly acid sandy loam is best, although somewhat heavier soils may produce better flowers. Use superphosphate, 5 pounds per 100 feet of row, applied in furrow and covered before planting. A 2-10-10 or 2-12-6 fertilizer may be added, 2 pounds per 100 feet of row when plants are 8 to 10 inches high.

Iris. Medium to heavy loam soils are best. Incorporate liberal application of manure when the soil is prepared. Add superphosphate, 4 to 5 pounds per 100 square feet before planting. An 8-5-3 fertilizer, 2 pounds per 100 square feet, should be used early in the spring, and a 2-10-10 at the rate of 3 pounds per 100 square feet applied after blooming.

Lilies. For this crop the soil types are variable, but deep preparation is beneficial. Incorporate superphosphate, 4 pounds per 100 square feet before planting. Add 2-10-10 or 4-12-4, 3 pounds per 100 square feet each spring.

Peonies. Heavy loam is best for flower production; light soils, for the production of roots. Deep preparation is essential. Incorporate well-rotted manure and 2-10-10, 4 pounds per 100 square feet at time of preparation. Add 2-10-10, 2 to 3 pounds per 100 square feet when growth shows above ground and again after blooming.

Spring-flowering bulbs. Well-drained silty or sandy loams are best. Incorporate superphosphate, 5 pounds per 100 square feet before planting. Add 4-12-4, 2 pounds per 100 square feet early each spring.

SHRUBS, OTHER THAN ROSES

Much variation is found in soil requirements. Thorough preparation of the soil and the incorporation of well-rotted manure and superphosphate, 10 pounds per 100 square feet, are desirable before planting. Add 10-6-4 or 4-12-4, 2 to 4 pounds per 100 square feet of bed area each spring. For specimen shrubs, use 1 to 2 pounds per plant. Further applications should be based on soil tests.

ROSES

Clay or clay-loam soils are favored but not necessary. Incorporate well-rotted manure or peat at time of soil preparation. Application of fertilizers should be based on soil tests. General recommendations are as follows:

1. Superphosphate, 4 pounds per 100 square feet in spring as growth starts. Potassium chloride, 1 ounce per 2 gallons of water (apply to 12 square feet) 2 to 3 weeks later. Ammonium sulphate, 1 ounce per 2 gallons of water (apply to 12 square feet) 1 week later, and follow with similar doses once a week. Or

2. A 4-12-4 or 6-8-6, 2 pounds per 100 square feet two or three times during the season.

EVERGREENS

Incorporate well-rotted manure or peat moss at time the soil is prepared. Well-rotted manure or peat used as a mulch over winter may be incorporated each spring.

Narrow-leaved Evergreens

Small plants. Use tankage or cottonseed meal, 5 to 6 pounds per 100 square feet of bed area each spring.

Large plants. Use 10-6-4 or 4-12-4, 2 to 4 pounds per 100 square feet of bed area each spring. Hoe or water in the fertilizer. For specimen plants of shrubby type, apply ½ to 1 pound per plant twice a year, early spring and about June 15. For specimen trees use 2 to 2½ pounds per each inch in diameter of the trunk.

Broad-leaved Evergreens

For many types the soil must be acid, so no materials that tend to neutralize the soil reaction should be used. The following are specific recommendations for azaleas and rhododendrons:

1. Select hardy plants. Use either native types or hardy hybrids.

2. Locate the beds with a northern or eastern exposure if possible. Protect from sweeping winds.

3. Select a light loam soil that is acid in reaction.

4. Excavate bed areas to 2 or 2½ feet. Provide ample drainage, and build a soil bed 4 to 6 inches above normal grade.

5. Supply liberal quantities of humus by incorporating, and adding as a mulch, acid peat moss or half-rotted oak leaves. In poor soils where additional fertilization is necessary, add well-decayed manure, cottonseed meal, or tankage. Tankage or cottonseed meal applied at the rate of 5 pounds per 100 square feet is excellent for small plants. For large plants use a 4-12-4 fertilizer in which cottonseed or soybean meal is used to supply ½ to ¾ of the nitrogen. Apply at the rate of 2 to 4 pounds per 100 square feet of bed area. Water in the fertilizer. For large specimen plants follow the same rate of application as given for narrow-leaved evergreens.

6. To maintain an acid reaction (pH 4.5 to 6.5) add finely ground sulphur or aluminum sulphate.

7. Maintain a cool, moist soil by providing partial shade and a peat or leaf-mold mulch.

8. Provide some protection in the winter from hard drying winds and excessive sun exposure. Mulch heavily.

9. Roots of most broad-leaved evergreen plants are located very near the surface of the soil and should not

be disturbed. Mulch rather than cultivate. Keep roots moist and cool.

10. Be sure that the plants are supplied with sufficient water before the ground freezes in the fall; never let them go into the winter in a dry condition. Water during thaws in winter.

TABLE III

APPROXIMATE AMOUNTS OF SULPHUR OR ALUMINUM SULPHATE PER 100 SQUARE FEET NECESSARY TO INCREASE THE ACIDITY OF A SILT LOAM

pH	Sulphur, pounds	Aluminum sulphate, pounds	pH	Sulphur, pounds	Aluminum sulphate, pounds
8.0–7.0	2.0	4.5	7.0–6.5	1.5	2.5
8.0–6.5	3.0	7.0	7.0–6.0	2.0	5.5
8.0–6.0	4.0	10.0	7.0–5.5	3.5	9.0
8.0–5.5	5.5	13.5	7.0–5.0	5.0	13.0
8.0–5.0	7.0	17.5	6.5–6.0	1.5	3.0
7.5–7.0	1.75	3.5	6.5–5.5	2.5	6.5
7.5–6.5	2.0	5.0	6.5–5.0	4.0	10.5
7.5–6.0	3.5	7.5	6.0–5.5	1.5	3.5
7.5–5.5	5.0	11.5	6.0–5.0	3.0	7.5
7.5–5.0	6.5	15.5	5.5–5.0	1.5	4.0

TREES

Much variation exists in soil requirements. Thorough preparation of the soil and the incorporation of well-rotted manure or peat moss and superphosphate (5 pounds per inch in diameter of tree trunk) are desirable before planting of most types. Proper aeration and adequate moisture are required for growth. Fertilizer applications should be made in the fall

(Oct. 15 to Nov. 15), although spring is satisfactory, using 12-6-4, 10-6-4 or Ammo-phos (11-48-0).

The rate of application for small trees, less than 6 inches in diameter, should be ¼ pound of available nitrogen per each inch in diameter of tree trunk.

For large trees, more than 6 inches in diameter, use ½ pound of available nitrogen per each inch in diameter of tree trunk.

Examples: 12-6-4, approximately 2 to 4 pounds per inch; 10-6-4, approximately 2½ to 5 pounds per inch; Ammo-phos, 11-48-0, approximately 2¼ to 4¼ pounds per inch.

The frequency of application will depend on kind of tree and growth responses, but for safety yearly treatments should be given.

The methods of application are: For small trees that have soil worked around them, broadcast the fertilizer, and hoe or water in. For larger trees use the "aero-fertile" method, by which the fertilizer is forced into the soil by means of compressed air. If water can be added at the same time, it will be beneficial, at least under dry soil conditions.

The punch-bar method is the most common. Apply in holes distributed evenly beneath the spread of the branches and over an area beyond the spread of the branches equal to half the spread of the tree. Dig approximately ten holes per each inch in diameter of the tree trunk. Make holes 15 to 18 inches deep with a soil auger or crowbar. Place the fertilizer in the holes which are then filled with soil.

Chlorosis of Pin Oaks and Other Ornamental Trees

Chlorosis may be overcome by making soil applications of ferrous sulphate and sulphur at the rate of ½ pound of each per inch in diameter of the tree trunk. A quicker reaction may be obtained by substituting aluminum sulphate for one-half the sulphur. The applications should be made according to the punch-bar method. Make applications early in the spring and as soon as the trees show the first symptoms of chlorosis. Applications of a complete fertilizer and an ample supply of moisture likewise will be beneficial.

GREENHOUSE SOIL MANAGEMENT

In field preparation of soil the important thing to remember is the addition of organic matter. For greenhouse purposes the amount of organic material supplied by a given crop is of greatest importance. The following steps should be taken in preparing the soil in the field: (1) Apply a good application of manure, (2) add 1,000 pounds of superphosphate, and (3) plow to a depth of 6 inches. (4) Test for acidity, and apply ground limestone if necessary. (5) Apply 500 pounds of potash to the acre. (6) Fit the soil, and sow soybeans. (7) When the pods form, plow the soybeans under. (8) Sow rye, 2 bushels to the acre. (9) Plow the following spring as early as possible. If no manure is available, apply a complete fertilizer at the rate of 500 pounds per acre.

After you have a good basic soil with plenty of organic matter present, you may easily vary the soil mixtures. In soil mixtures we find that greenhouse cut-flower crops are not so exact as pot plants. One must study the various plants and then see in what type of mixture they will grow best. The poinsettia requires a soil that drains quickly; therefore no peat should be added to the soil. For cyclamen peat is useful. Many plants may be grown with less trouble from watering if the proper soil mixture were used at the start.

Watering Methods Important

An important factor in the care of a greenhouse soil is the method used in watering. The greenhouse soil must obviously have a satisfactory means of drainage. With this essential feature present, the proper way to water a crop is by giving the soil a good thorough soaking whenever the need exists. This serves to keep the pores of the soil free from toxic materials, gives air a chance to penetrate well into the soil in between waterings, and keeps the soil in a healthy condition for root development. Daily watering introduces a factor of soil saturation. The amount applied at one time is small and insufficient to penetrate deeply. Consequently, the few inches of top soil remain constantly wet, thus preventing the normal penetration into the soil below. Such a root system is limited in its supply of nutrient materials and will suffer quickly if the water supply is cut off or if outside factors develop a transpiration rate beyond the capacity of the roots to take in water. The lower part of the soil becomes not only useless to the plant but also a storehouse for the unleached chemicals, both toxic and beneficial. To avoid this condition 2 inches of coarse, well-leached cinders or gravel is placed in the bottom of the bench instead of the usual straw or manure.

Another factor connected with watering is the temperature of the water used. In a warm house, for the optimum growth, the water applied should be at house temperature or slightly higher. Cold water will impair normal growth, as roots should be in an environment at least as warm as the rest of the plant. Evaporation of water from soil is another factor tending to keep the soil cooler than the atmosphere, and the application of a water slightly warmer than house temperature will tend to counteract this.

Soils and Fertilizers for Greenhouse Crops

The appended table is intended to familiarize the grower with the most up-to-date practices in the selection of soils and fertilizers for the most important crops. Since soils vary greatly in the factors of fertility, texture, structure, water-holding capacity, etc., it is impossible to follow exactly the directions given. Some modifications will have to be made in individual instances. The good grower intimately in touch with his plants should be able to recognize the deficiencies in the soil and apply fertilizers in accordance. The plant itself is the best indicator of all needs. Watch it.

The term "heavy" soil refers to a silt or silty clay soil. Silt soil is constructed of very fine grains but not so fine as those making up clay. When a silt soil dries, the resulting lump can be crushed with the fingers. A real

FERTILIZER REQUIREMENTS FOR SPECIAL CROPS

Name	Optimum pH	General fertilizer requirement	Rate of application	P.p.m.
Major Crops				
Carnations	6.0–7.5	Superphosphate or bone at planting. Tankage or 4-12-4 in fall and spring. Ground limestone	5 lb. to 100 sq. ft. 3 lb. to 100 sq. ft. 3 lb. to 100 sq. ft.	N 5–15 P 2–10 K 15–25
Chrysanthemum	5.5–7.5	Superphosphate at planting. Peat as a mulch. Ammonium sulphate when test shows its need	5 lb. to 100 sq. ft. ½ in. thick 1 lb. to 100 sq. ft.	N 10–25 P 5–10 K 10–25
Rose	Slightly acid in spring and summer and near neutral point in fall and winter 5.5–7.0	Superphosphate or bone at planting. Manure mulch, tankage or alternate ammonium sulphate and 10-6-4 when soil shows need by testing	5 lb. to 100 sq. ft. 4 lb. to 100 sq. ft. 1 lb. to 100 sq. ft. Double the dosage in spring	N 25–50 P 5–10 K 25–50
Minor Crops				
Bouvardia	6.0–7.0	Superphosphate at planting. Later 4-12-4	5 lb. per 100 sq. ft. 3 lb. per 100 sq. ft.	N 5–15 P 2½–5 K 10–15

Buddleia	6.0–8.0	4-12-4 at planting	....	N 5–25 P 5–10 K 10
Calendula	6.5–7.5	Superphosphate at planting. Ammonium sulphate when needed. Mulch of peat desirable	10 lb. per 100 sq. ft. 1 lb. to 100 sq. ft.	N 10–25 P 5–10 K 10–20
Euphorbia fulgens	6.5–7.5	Superphosphate at planting. Nitrophoska	10 lb. to 100 sq. ft. 1 oz. to 2 gal. of water	N 5–15 P 2½–5 K 10
Gardenia	5.5–6.5	4-12-4 at time of planting. Mulch of acid peat. Ammonium sulphate fall and spring. Iron sulphate	4 lb. to 100 sq. ft. 1 in. deep 1 lb. to 100 sq. ft. ½ lb. to 100 sq. ft.	N 10–25 P 5–10 K 10–25
Snapdragon	6.5–7.5	Superphosphate at planting. Ammonium sulphate at intervals for second crop. Mulch of peat or well-rotted manure in spring	10 lb. to 100 sq. ft. 1 lb. to 100 sq. ft.	N 5–10 P 5–10 K 10–20
Stocks	6.5–7.5	4-12-4 at planting. Ammonium sulphate when needed	4 lb. to 100 sq. ft. 1 lb. to 100 sq. ft.	N 10–25 P 2½–5 K 10–25

Name	Optimum pH	General fertilizer requirement	Rate of application	P.p.m.
		Minor Crops (*Continued*)		
Sweet Peas...........	6.0–7.5	Lime at planting, if needed. Superphosphate at planting. Add sodium nitrate at end of season	5 lb. to 100 lin. ft. 5 lb. per 100 lin. ft. 1 lb. per 100 lin. ft.	N 10–25 P 5–10 K 15–25
		Annuals		
Aster...............	6.0–7.5	4-12-4 at planting. Applications of 4-12-4 during the growing season	4 lb. to 100 sq. ft.	N 5–10 P 2½–5 K 5–10

Boston yellow daisy	Gypsophila	Pansy
Candytuft	Larkspur	Salpiglossis
Centaurea	Marigold	Scabiosa
Chrysanthemum (annual)	Marguerite	Schizanthus
Clarkia	Mignonette	Statice
Didiscus	Myosotis	Venidium
Feverfew	Nemesia	Zinnia
Godetia		

(Same as Aster, above)

Important Pot Plants

Begonia (Melior)	6.0–7.0	4-in. pot horn shavings and 4-in. pot 4-12-4 to wheelbarrow of soil	Do not use peat in acid soils	N 5–10 P 2½–5 K 5–10
Calceolaria	6.0–7.5	4-in. pot 4-12-4 to wheelbarrow of soil	No peat	N 5–10 P 2½–5 K 10
Cyclamen	5.5–7.0	4-in. pot horn shavings in early potting, 4-12-4 in later potting. Ammonium sulphate after final shift	. . . .	N 10–25 P 2½–5 K 10–25
Cineraria	6.0–7.0	4-12-4 at potting and in every shift	Do not use peat in small sizes	N 10–25 P 5–10 K 10–25
Fern	6.0–7.0	4-in. pot horn shavings in early shifts. 4-12-4 later, and regular applications of ammonium sulphate in liquid form	. . . .	N 10–25 P 2½–5 K 10–25
Fuchsia	6.5–7.5	4-12-4 at final shift	. . . .	N 5–10 P 2½–5 K 10

Fertilizer Requirements for Special Crops (*Continued*)

Name	Optimum pH	General fertilizer requirement	Rate of application	P.p.m.
Important Pot Plants (*Continued*)				
Genista	6.5–7.5	15-30-15	Biweekly 1 oz. to 2 gal. water	N 5–10 P 2½–5 K 10
Geranium	6.0–8.0	Superphosphate, 2-10-10 final shift	4-in. pot to bushel, 4-in. pot to wheelbarrow	N 5–10 P 2½–5 K 10
Hydrangea	Blue: 4.5–5.5 Pink: 6.0–7.0	Superphosphate 4-in. pot 4-12-4 and 3-in. pot aluminum sulphate, provided soil is alkaline, to wheelbarrow of soil	4-in. pot to bushel. 1 lb. aluminum sulphate to 5 gal. water if blue color is desired. Apply this at least three to four times during forcing season	N 10–25 P 5–10 K 10–25
Lily	6.0–7.0	Ammonium sulphate when needed	1 oz. to 2 gal.	N 5–10 P 5–10 K 5–10

Name	Optimum pH	General fertilizer requirement	Rate of application	P.p.m.
Important Pot Plants (*Continued*)				
Primula	6.5–7.5	4-in. pot 4-12-4 per wheelbarrow of soil	No peat	N 5–10 P 2½–5 K 10
Poinsettia	6.0–7.5	4-in. pot superphosphate per wheelbarrow of soil. Liquid fertilizer after flower forms	....	N 5–10 P 5–10 K 10–20
Rose	6.0–7.0	4-12-4 at potting	....	N 10–20 P 5–10 K 10–20
Saintpaulia	6.5–7.5	4-12-4 at final shift	Do not overshift. Grow well shaded in summer	N 5–10 P 2½–5 K 5–10

clay soil, on the contrary, cannot be so crushed when dried. Loams always contain more sand and hence are not classified as heavy soils. Where one is so fortunate as to have a sandy soil, the addition of sand to the soil mixtures is not necessary.

Manure is to be used only in the well-rotted stage. Its chief value is not as a fertilizer, but as a soil conditioner, as it helps loosen the heavier soils and also acts as a source of favorable bacteria that are necessary for plant growth. Well-rotted cow manure should be used in preference to other kinds.

In using manure as a mulch, remember that fresh manure has to be broken down and this can be accomplished only by bacteria which in turn feed on nitrates. These nitrates are taken from the soil for this decomposition. When it is necessary to use fresh manure (which is not recommended), apply some form of nitrogen, such as ammonium sulfate or sodium nitrate, to the soil. Mulches are helpful in preventing the soil from drying out too quickly.

The fertilizer recommendations given in the table are of a general nature, but it will be noted that parts per million of the three elements are suggested. This has been done because of many requests. Considerable leeway is suggested in the parts per million column, simply because a wide range of nutrition is possible. Hence these recommendations would have to be modified for different localities where greater sunlight, higher humidities, and extreme temperatures may obtain. However, in general, the recommendations will work.

It should be remembered that higher amounts may do no harm but are wasteful. *The parts per million as recommended are based on the use of the Edwards Simplex Soil Kit or the Morgan-LaMotte Kit. Be sure not to confuse parts per million with pounds per acre. If you wish to translate the parts per million to pounds per acre, multiply the parts per million by* 8.

Wherever ammonium sulphate is recommended, nitrate of soda or calcium nitrate may be substituted in soils that have a tendency to become too acid from the continual use of ammonium sulphate.

Since on the pH range depends the availability of the various elements, it may differ in many soils. For that reason considerable leeway is again suggested in the table.

Specific soil mixtures have not been indicated, because it is impossible to make recommendations for all localities where great variation of soil types exists. Usually an addition of one-fifth to one-fourth well-rotted manure is desirable. Leaf mold is useful particularly with saintpaulias and azaleas, whereas peat is needed for gardenias, hydrangeas, cyclamen, and begonias.

Excesses of Fertilizers

With the advent of the fertilizer era, our troubles with overfertilization really began. The innocent-looking salts that comprise our fertilizers are potent indeed and unless used with proper precautions are extremely dangerous. Inaccurate weighing out of materials; the feeling that if a little is good, a lot is better; failure to recognize needs of the plants; lack of soil testing; lack of coordination with moisture, light, and temperature—all these are among the factors that have been responsible for the overdosing of soils with quick-acting fertilizers. The symptoms of these overdoses are frequently difficult to distinguish from nutrient deficiencies or other cultural defects, but some are sufficiently outstanding to warrant presentation.

GENERAL SYMPTOMS OF FERTILIZER EXCESSES

Ammonium Sulphate

All symptoms begin at the bottom of the plant. Stunting of the plant is accompanied by short internodes, small leaves, and flowers. Leaves brown at the margin and gradually turn yellow. At first the foliage may turn extremely dark blue-green. Wilting is noticeable in herbaceous plants. Crinkling of leaves develops in certain crops.

Rose. Leaves are light green between veins. Veins are green. New leaves are light yellow with pink tint.

Chrysanthemum. Browning of edges, wilting, stunted appearance, and complete yellowing of new leaves are symptoms.

Snapdragon. Tips of plants wilt. Top leaves become yellow. Shriveling of the tip occurs.

Sweet Pea. Characteristic appearance is blue-green, small leaves, purple tendrils, short internodes. Roots become brown at ends.

Calendula. Stunting develops. At first, plants are dark green with lower leaves becoming brown at tips. The midrib crinkles. Wilting is excessive.

Stocks. Effect is very injurious, resulting in severe stunting and bluish-green foliage. Wilting is serious. Leaves droop. Older leaves turn brown.

Cineraria. Plants wilt rapidly. They are markedly stunted. Leaves are small, and veins dark with yellow interspaces. Brown spotting develops both in margins and throughout the entire leaf area.

Feverfew. Lower leaves turn yellow and then brown. Tips of new leaves are yellow. Margins become brown. General stunting develops.

Cyclamen. Older leaves wilt; leaf tips and margins become brown.

Gardenia. Older leaves are yellow between veins. Marginal browning and brown spotting occurs, which is very typical, between veins. Defoliation is present.

Begonia. Stunting and basal rot develop. Leaves turn yellow at base and drop.

Poinsettia. Older leaves yellow. Foliage drops progressively upward. Stems are soft. Leaves curl inward.

Azalea. Lower leaves become leathery and turn yellow with brown margins. Later the entire leaf turns brown, curls inward, and finally drops off.

Calceolaria. Lower leaves become brown. Top foliage is extremely dark green. Flowers are small.

Lily. Plants are stunted; leaves, narrow and small. The latter become yellow at the top of the plant, brown at the base. Buds and flowers are small.

Annuals (Centaurea, annual chrysanthemum, candytuft, larkspur, dahlia, salpiglossis, aster, godetia, didiscus). Stunting, yellowing of leaves, browning at margins, and excessive wilting are all symptoms of ammonium sulphate overdoses in these annuals.

Nitrate of Soda

Marked stunting, short internodes, small leaves, and small flowers are symptoms. These first appear at the bottom and gradually work upward. Leaves turn yellow with brown margins. Sometimes the entire leaf turns brown. Excessive wilting occurs.

Rose. Edges of leaves turn brown, with yellow streaks between the veins. New leaves are larger than normal, light green, and soft in texture. They are wider in proportion to length than normal.

Chrysanthemum. Chlorotic areas appear in younger leaves. New growth has rosette effect. Wilting occurs.

Snapdragon. Plants are stunted. Young leaves are yellow. Old leaves are dark green with brown spots. The top shrivels.

Sweet Pea. Symptoms are similar to those caused by ammonium sulphate.

Calendula. Symptoms are similar to those caused by ammonium sulphate but more pronounced.

Stocks. Growth is stunted. Lower leaves turn yellow. Veins become yellow. Foliage drops quickly, beginning at bottom.

Cineraria. Growth is stunted. Lower leaves wilt.

Leaves are small with short petioles. Marginal browning and cupping of the leaves.

Feverfew. Lower leaves brown and die. All foliage becomes yellow. Plants are stunted and wilt.

Cyclamen. Symptoms are similar to those caused by ammonium sulphate.

Gardenia, begonia, poinsettia, azalea. Symptoms are similar to those caused by ammonium sulphate.

Calceolaria. Older leaves turn brown. Top foliage becomes yellow with tips of growing points bright yellow. Browning progresses from the bottom until the entire plant dies.

Lily. Symptoms are similar to those caused by ammonium sulphate.

Annuals. Symptoms are similar to those caused by ammonium sulphate.

Potassium Chloride

The plants are dwarfed with short internodes, small leaves. Stems are weak, and flowers small. Maturity is delayed. Yellowing of the foliage begins at the bottom and progresses upward. The yellow leaves turn brown at the margins and finally become completely brown. Shriveling of the entire plant occurs in the final stages.

Rose. Light brown color develops along the margins of leaves. The new leaves are light green. Wood becomes hard.

Chrysanthemum. Slight stunting and dwarfing occur.

Snapdragon. Leaf petioles wither, and cause leaves to hang down along the stems. Growing points become yellow. Stunting is less marked than in the case of nitrogen excesses.

Sweet Pea. Terminal growth becomes yellow. Roots are injured.

Calendula. Lower leaves yellow. Complete yellowing of the plant occurs later. Tips of leaves turn brown and somewhat crinkled. Additions of organic matter reduce symptoms.

Stocks. Foliage becomes stunted and yellow. The lower leaves become bright yellow. Lateral shoots develop early, even in nonbranching varieties.

Cineraria. Entire plant yellows, starting at the base. The color is more intense than in nitrogen excesses. Lower leaves have dark margins and become cup shaped.

Feverfew. General yellowing and stunting occur. Leaves show brown tips. The plant wilts.

Cyclamen. Wilting occurs. Petioles and peduncles become soft. Leaves yellow.

Gardenia. Young growth is affected first. The leaves turn yellow with marginal browning, starting at the tip. Rapid defoliation results.

Poinsettia. Lower leaves turn yellow and drop. Defoliation is not so severe as in nitrogen excesses.

Calceolaria. Effect similar to nitrogen excesses but much more severe, resulting in extreme stunting and delayed flowering.

Lily. Plants are dwarfed. Foliage yellows. Lower leaves turn brown. Buds are large. Flowering is delayed.

Annuals. Complete yellowing of plants occurs, with stunting and wilting.

Phosphorus (Superphosphate, Treble Phosphate, and Monocalcium Phosphate)

Extremely high concentrations of superphosphate (20 per cent) are necessary before any damage occurs. Treble phosphate (45 per cent) shows greater damage. In general, early maturity results. The first symptoms are browning of older bottom leaves, usually at the tips and margins. Shriveling of lower leaves occurs together with a paper-like appearance. Sometimes leaves appear puffed, as in fuchsia.

Rose. Growth, hardens but no visible symptoms appear on foliage.

Chrysanthemum. Lighter green leaves are the only symptom.

Snapdragon. Tips become lighter green. Terminal growth is killed eventually. Younger leaves die. Flowers become malformed and discolored.

Sweet Pea. Marginal leaf injury is followed by drop. Vigorous terminal growth occurs, but no real injury.

Calendula. Lower leaves turn to white, parchment-like tissue. Numerous side branches develop. Early flowering. Upper leaves are large; internodes, long.

Stocks. Stems become hard; foliage, gray-green. Lower leaves eventually drop as excess increases. Early flowering takes place.

Cineraria. Lower leaves turn yellow and later reddish brown. Another characteristic is early maturity.

Feverfew. Little effect occurs except yellowing of lower foliage.

Cyclamen. Petioles and peduncles are shortened. Early flowering takes place. No noticeable damage.

Gardenia. Excess shows slowly and is indicated by light brown margins of older leaves.

Begonia. This overdose has no effect.

Poinsettia. No ill effects result. Bracts color much earlier.

Azalea. Marginal browning of lower leaves is a characteristic. Young leaves are chlorotic, later becoming spotted with brown. The effects show slowly.

Calceolaria. Rapid wilting and browning of the entire plant occur.

Lily. There is no effect except early maturity and browning of lower leaves.

Annuals. Slow stunting accompanied by yellowing and later browning of lower leaves is to be expected. Tips of leaves become paper-like. Stems become reddish. There is early maturity in all cases.

Trace Element Excesses of the Rose

Boron (Fig. 6). Browning of the teeth of the leaf blade occurs, with black spots which may be mistaken for the disease known as "black spot." Brown intervenal spots and splotches appear. The older leaves yellow and are affected first. All leaflets fall, leaving the

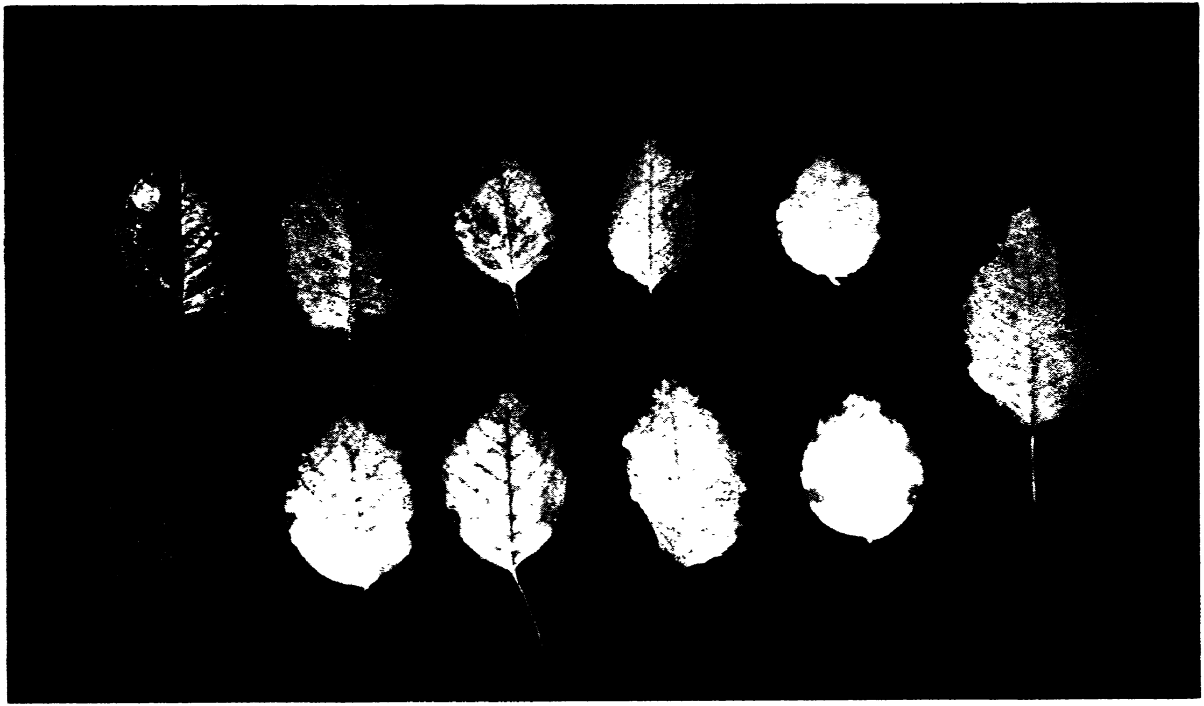

Fig. 6.—Excess of boron in the rose.

Fig. 7.—Excess of zinc in the rose.

midrib. The symptoms proceed from the base of the plant upward.

Zinc (Fig. 7). Water-soaked areas appear along the mid-vein and main veins of leaves. These areas are transparent when held to the light. The foliage becomes light green with yellowing or browning of the area between the veins. The midrib remains greenish and distinct after the rest of the leaf turns yellow. Usually the leaflets yellow one by one. Damage starts at the base.

Copper. General yellowing of lower foliage occurs, followed by brown discoloration of the central leaflets, which drop gradually, producing a onesided appearance.

Excesses in the Tomato[1]

Boron. Symptoms are slow to appear. Burning of the margins occurs on lower leaves.

Calcium. Plants are weak; the leaves, long and slender. Terminal shoots are poorly developed.

Magnesium. This overdose has no effects except light brown pin spots on the stems, causing no apparent damage.

Potassium. No effect is noticeable.

Nitrogen. Excessive vegetative growth occurs at the expense of fruiting. Terminal shoots are depressed. There is abundant lateral branching. Leaves are spotted

[1] *Maryland Agricultural Experiment Station Bulletin* 375, 1935.

with dead areas, curled, and pimpled and yellowed between veins. Maturity is delayed.

Phosphorus. No effect appears except for slight reduction of vigor.

Sulphur. Leaves are roughly pimpled, curling inward. Lower leaves are marginally browned. Terminal growth is pale yellow

Chapter V

HOW PLANTS GROW

A PLANT is an organism composed of cells which are grouped into various tissues, each having certain functions to perform. Like human beings, plants expend energy and do work. Moving pictures taken at intervals have demonstrated how roots twist and turn through the soil and around particles, how stems and leaves weave rhythmically, how they turn toward light. The plant is composed of a number of organs which function in various ways: The roots act as the absorbing organs; the stems are the conductors of food and provide support; the leaves manufacture food and lose water; and the flowers envelop the reproductive organs.

Roots perform one of the most important functions—that of absorbing water and nutrients from the soil and acting as anchors. Root tips are covered by numerous root hairs which actually do the absorbing. Their life is short; and as the root develops, new root hairs are formed while the old become useless and slough off. Because of these tender hairs any transplanting operation is attendant with danger, since many of these absorbing organs are killed by removal of the plant from the soil, and time is needed to develop a new set for the continuance of the growth of the top.

The root hairs curve about the soil particles and by this close contact absorb the needed nutrients and water. These materials pass into the root hairs and thence through other cells into all parts of the plant. It is important to note that the concentration of the cell sap contained in the root hairs is more dense than that of the soil. Because of this condition the water passes from the soil through the cell walls, since the passage is from the weaker to the stronger solution. Should the soil solution become more concentrated than the cell sap, water will pass from the cell into the soil. This causes "wilting"; and if the condition continues, it will be followed by death of the root hairs and eventually of the roots. Such a condition occurs in alkali soils or in the greenhouse when the concentration of soluble salts gets beyond the limitation of cell-sap concentration. As indicated previously, satisfactory soils are those which contain a sufficiency of air, moisture, and the proper degree of temperature for the development of roots and root hairs.

The leaves perform the function of food manufacture and are dependent for effective performance upon light, moisture, supply of carbon dioxide, and temperature.

Photosynthesis

The chief function of the sun is to supply energy. This energy is used by the plant in manufacturing plant foods such as sugar, starch, proteins, and fats. The name "photosynthesis" (a synthesis utilizing light) has been given to it. Carbohydrates are made by the plant in the chloroplasts. Any part of the plant that contains chlorophyll and is exposed to light can carry on the process. The outstanding organs of photosynthesis, however, are the leaves.

From the chemical composition of carbohydrates, it is evident that there must be a supply of carbon, hydrogen, and oxygen for their synthesis. All these elements are obtained from two compounds, water and carbon dioxide. No other compounds obtained from the air are used in photosynthesis. Ordinarily, plants obtain their water from the soil. It is absorbed by the roots and conducted from them through the stem to the leaf. A special tissue, the xylem, is used for this purpose. The xylem vessels which form the plants' water system are essentially a network of very fine tubes beginning in the roots, ending in the leaves, and containing branches to all parts of the plant, so that every cell is in close proximity to its water supply.

The carbon dioxide enters in gaseous form from the atmosphere, gaining entrance to the leaf through the stomata, or leaf pores. Soils ordinarily contain more carbon dioxide than is found in the atmosphere, but it is very improbable that any of this carbon dioxide of the soil is absorbed by the roots and used in photosynthesis. Ordinarily carbon dioxide exists in the atmosphere in rather small quantities, averaging three parts in 10,000 parts of air. Ventilation of the greenhouse is very necessary to keep the concentration up to normal. The light is the limiting factor in the winter; therefore additional carbon dioxide would not hasten growth. If additional light is used, carbon dioxide shows more positive results.

The rate at which carbohydrates are made by the plant depends upon the combined action of external and internal factors. The most important external factors are temperature, carbon dioxide supply, the kind and amount of light, and the water supply. Two internal factors are important: the chlorophyll content and the action of a specific enzyme associated with the process.

In general, as the temperature rises above the minimum, the rate of photosynthesis rises in a geometrical ratio; *i.e.*, for every 10° rise in temperature the rate of photosynthesis increases 2 to 2.3 times until a temperature of 85 to 95°F. has been reached, beyond which no further increase in the rate occurs. If the temperature rises above 85 to 95°F., the rate may decrease.

Probably no other single external factor under natural conditions has a greater influence on the rate of photosynthesis than the carbon dioxide supply of the atmosphere. As previously stated, there is only three-hundredths of 1 per cent of this gas in the air. When it is artificially supplied, many common plants increase in weight until a concentration of about 0.5 to 1 per cent of the air is carbon dioxide. When the fact is borne in mind that this carbon dioxide is the only source of carbon for the plant and that carbon makes up about 50 per cent of the dry weight of the plants, the importance of an ample supply of the gas becomes apparent. The application of additional amounts of carbon dioxide to crop plants has been tried by many investigators, and from 30 to 300 per cent growth increases have been recorded.

The rate of photosynthesis increases as the intensity of light increases, up to a maximum point. Plants vary considerably as to this maximum point, but for most of them it is far below the intensity of daylight at noon. It has been found that noon daylight intensity during the summer can be reduced to one-twelfth its value before any decrease in the rate of photosynthesis occurs. Rose growers producing a summer crop have tried shading the glass and have had much better results. It should be noted that intensity begins to decrease rapidly after Aug. 15 and also that shade should be decreased gradually.

The duration of the light, or the length of time the plant is in the light, will obviously affect the amount of carbohydrates produced. This factor becomes important during the short days of autumn and winter. It is of considerable practical importance in the production of greenhouse crops in winter.

Water being one of the raw materials of which the carbohydrates are formed it is easily seen that a deficiency of water might check the rate of photosynthesis. Only when water becomes so low as to cause wilting, however, does this factor become important.

Ordinarily it is doubtful if the water supply of plants becomes a limiting factor in the process.

It should be kept in mind that all these factors are operating simultaneously and that the amount of carbohydrates made will depend upon their joint action. Yet, as a chain is no stronger than its weakest link, so the rate of photosynthesis in the last analysis is probably determined by that factor which occurs in minimum.

The carbohydrates—made, as explained, by the process of photosynthesis—are used by the plant in digestion, translocation, respiration, synthesis of other substances, assimilation, and food storage.

Respiration

Another important activity in the plant is the process of respiration. Just to look at a rose growing, one probably would never imagine that within its tissues so many different and important metabolic processes were taking place. These processes are enabling the plant to extend its roots through the soil, raise its stem and leaves into the air, and develop and open its flowers. Of course, the green plant "has something on" us when it comes to manufacturing sugars and starches from raw materials, such as water, carbon dioxide, nutrients, and sunlight. The human organism cannot do that. But we do respire in much the same way that every plant breathes, and about the same factors influence alike our respiration rates and theirs.

In the first place, what is respiration? Defined in a simple manner, it is nothing more than the absorption of oxygen and the release of energy, carbon dioxide, and a small amount of heat. This type of respiration is known as "aerobic" (in presence of oxygen) and is most common in plants. Anaerobic respiration (in absence of oxygen) is less common. Usually it is undesirable, since materials toxic to the living tissues are generally developed when it occurs. Respiration takes place both day and night, light or no light. Essentially it is the breaking down of food material in the leaves, or, in other words, the opposite of photosynthesis, which is the building up of foods. The process of *respiration* is just as *important* to the growing plant as photosynthesis, since the accumulated food would be of no value unless its *energy* were released for growth. This energy is absolutely necessary for the shoot as it moves upward and for the flowers as they swell in the bud and open.

However, respiration can be harmful when it proceeds at too fast a rate or beyond the actual energy needs of the plant. Food is thus burned up more rapidly than it is accumulated by photosynthesis. The one most important environmental factor that causes high respiration is high *temperature*. Within reasonable limits, the higher the temperature the faster the rate of respiration. For example, in the case of the rose, respiration is more than twice as fast at 80°F. as at 50°F. At 90°F. it is about four times as fast as at 50°. This has a definite bearing on the intake of nutrients during summer. *The weakened condition of plants makes heavy fertilization at that time undesirable.*

Generally speaking, the younger, more actively growing plant tissues respire faster than do the older, basal portions of the plant. Increased respiration is also associated with flowering plants as compared with nonflowering plants. In the case of bulbs we know that respiration is very closely associated with the breaking of the rest period. Bulbs are known to respire actively just at the time the period is broken and the stem and leaves appear. This is likewise true for seeds, and it is interesting to note that in case of honeylocust, Kentucky coffeebean seeds, and other hard-coated seeds, it is necessary to treat them with acids or scrape them so that oxygen may enter to create respiratory activity.

Movement of Sap in Plants

Materials move inside the plant in order to supply its needs. Thus water is conducted to the leaves from the soil, and manufactured foods are transported back to the roots for storage and use. The sap of the plant consists of water, minerals, and manufactured foods. The concentration of this sap varies in different parts of the plant. Because of this variation, movement takes place. For example, the high sap concentration of the leaves causes water to be constantly conducted to them from cells of lower concentration. The reason for the high concentration of the sap in the leaves is the constant loss of water through transpiration.

The movement of materials in the plants is a two-way affair. The upward stream, passing usually through the xylem, consists of water, mineral salts, and some foods carried from the roots and stems to other portions. The downward stream is composed of "manufactured" foods—sugars, starches, proteins, fats—and passes through the phloem. It is now believed that the phloem likewise is of service in the passage of materials upward.

Transpiration

Transpiration is often likened to evaporation, but it differs in that the living plant controls it, whereas evaporation goes on automatically. Thus we may find that dead plants evaporate more water than similar living plants transpire it. All exposed parts of the plant lose water vapor, but the leaves are the principal organs of transpiration.

One of the important functions of transpiration is the maintenance of a constant stream of water from the roots to the leaves. It is a mistaken idea that the greater the transpiration the greater the intake of nutrients. Actually water and nutrients are absorbed independently of each other, although both are taken in solution form. The water loss from the leaves occurs through pores, or stomata, which have the power to open and close. However, since the prime function of the stomata is to permit entrance of carbon dioxide, they are not always helpful in the control of transpiration. For example, they are fully open when the sun is shining, which is when transpiration occurs at the greatest rate. They are closed at night when transpiration normally would be lower. Saturation of atmosphere, particularly in the greenhouses, reduces the transpiration rate. Hence it is frequently resorted to during extremely warm summer days.

The Manufacture of Foods

The chemical changes that take place in the plant may be considered as forming two groups, or classes: the constructive group, which is represented by photosynthesis, producing sugars and elaborating proteins; and the destructive group—respiration breaking down the carbohydrates, releasing carbon dioxide and potential energy.

As we have noted previously, sugars are formed by photosynthesis in the leaves, but it is thought that the first product of this process is formaldehyde, which is immediately condensed into hexose sugars, and that these, through the action of enzymes, are changed to more complex compounds—carbohydrates—which, as the term indicates, are composed of carbon, hydrogen, and oxygen. These compounds are used as temporary foods to furnish the energy and materials for building plant tissues and as storage products for the future use of the plant.

Compounds similar to carbohydrates, but serving a different purpose, are the gums, pectins, and celluloses. These form the structural framework of the plant and are present in cell walls. They are probably elaborated from the carbohydrates.

Another group of compounds produced is the glucosides. These, because of their bitter taste, serve a protective purpose in the bark and immature fruits. The pigment glucosides are responsible for the high coloration of many flowers. Tannins, belonging to the same group, may likewise serve in the protective capacity as antiseptic agents through preventing attacks of parasitic fungi.

Practically all plants contain compounds known as "pigments." The chlorophylls are green; the carotinoids, flavones, and xanthones are yellow; lycopersicum and anthocyanin are red; anthocyanin derivatives are blue; and brown is characteristic of phycophaein and fucoxanthin. These various pigments play their role in the various metabolic processes that take place within the plants.

Organic acids are widely distributed in plants and are largely responsible for flavors in fruits. Fats form the most important energy supply in plants, whereas waxes are thought to be useful in the regulation of water losses from the leaves, stems, and fruits.

In addition to the compounds mentioned above, an extremely important group is the one that contains forms of nitrogen. These are known as "vegetable bases and proteins." The functions of the vegetable bases are not clear. Some authorities think that they are waste products of protein synthesis. Proteins are very important in the life of the plant. They form the active ingredient of protoplasm; in combination they are a part of the cell nucleus; they predominate in germ cells.

Thus it is evident that they are very vital to the well-being of the plants. Protein synthesis does not depend upon photosynthesis. It is accomplished by certain enzymes which condense amino acids into proteins—which are compounds composed of carbohydrates, nitrogen, sulphur, and phosphorus in varying ratios.

All these processes and changes are dependent largely upon the presence and action of enzymes—catalytic agents of chemical nature, building up synthetic materials and rendering foods soluble for translocation within the plant structure.

The discussion of plant growth in soil has been made detailed with a specific end in view, *viz.*, to familiarize the reader with the necessary fundamental factors involved. The following discussion of crops grown *without soil* is but an application of these same principles.

In soilless plant culture we substitute, for the soil, water and an inert substance, the former carrying the needed nutrients, the latter acting both for that purpose and as an anchorage for the roots. If plants are grown in water alone, we supply the needed aeration artificially; in sand or "gravel" this is taken care of automatically. The needed moisture is there in either case.

In this connection it should be noted that the organic matter—so important when plants are grown in soil—becomes unnecessary, because its functions are taken *care of automatically and the nutrients are provided in such form as to be readily available to the plant.*

Hence, for all practical purposes, plants develop under similar conditions, whether they are grown in soil, in water, or in some inert sterile substance plus water.

Chapter VI

COMMERCIAL GROWING OF CROPS IN SAND

AS INDICATED in Chap. II, sporadic attempts have been made by workers in several experiment stations to substitute sand for soil in commercial greenhouse culture. Although it is true that successful crops may be grown, the method has not proved sufficiently attractive to growers to induce many of them to make the change—largely because there was apparently little to be gained by the substitution. In some cases, however, results have been favorable, as will be seen from the following discussion by Biekart and Connors.[1]

COST OF PRODUCTION

"The cost of producing the same number of flowers (carnations) on a square foot in sand culture is lower than the cost in soil, and, moreover, the grower has a much greater control over the conditions of the plants. For 185 gallons of water, which is sufficient for 1,500 plants if used at the rate of 1 pint to a plant, the cost of the chemicals is only 24 cents a week. If this is taken on a 12-month basis, the total cost of the

[1] *New Jersey Agricultural Experiment Station Bulletin* 588.

chemicals for 1,500 plants is $12.48, or less than 1 cent a plant. This is about on a par with the cost of fertilizers in soil culture. But if one considers the time involved in applying fertilizers to soil and working it into the surface, it becomes apparent that the application of nutrient solutions is considerably cheaper, particularly when it is borne in mind that, while the solution is being applied to the sand, a watering is given at the same time. The preparation of the nutrient solution requires about 10 minutes.

"The cost of sand, as compared with composted soil at the time of benching, varies according to the location. In many sections, sand will be decidedly cheaper than composted soil; in other sections, it is probably more expensive or difficult to obtain.

"Sand may be left in the benches for at least 6 years without renewal, and from present indications it seems to offer a good growing medium for many more years to come. In most sections soil is replaced every year. This operation involves not only the cost of labor in emptying and refilling the benches, but also the building of a compost pile, for which good top soil, manure, and labor are required.

"Sand does not require weeding and cultivation, which are necessary operations in soil culture. Sand requires no more water than soil. When sand is watered the water is immediately absorbed, whereas when soil is watered, unless the bed is perfectly level, the water will run to the low spots, resulting in an uneven drying out of the bench. The wet spots favor the development of branch rot or stem rot, and the dry spots favor an infestation of red spider mite. The freedom of sand from organic matter is believed to be the cause of the less common occurrence of branch rot, stem rot, and rust in sand than in soil.

"All these statements point conclusively to the fact that the growing of carnations in sand is more economical than growing in soil and that the cost of installing a tank and the piping is more than offset by the other economies."

OTHER EXPERIMENTS

Our own experience has indicated similar possibilities, and for a number of years we were able to grow very satisfactory crops of roses, chrysanthemums, carnations, calendulas, stocks, and others by using washed sand (organic matter content about 2 per cent) of about the same coarseness as is used in the propagation of cuttings. The plants were planted directly from the cutting benches, spaced the same as in soil, and fertilized regularly every 2 weeks with a 15-30-15 (Nitrophoska) fertilizer to which magnesium sulphate was added. The rate of application was 1 pound of 15-30-15 and ⅕ pound of magnesium sulphate to 100 square feet. After trying many combinations, this commercial grade, together with the magnesium sulphate, was found to be most satisfactory, partly because it was highly soluble and because it contained enough impurities of trace elements to give us no troubles from any deficiency.

H. Hill of the Central Experimental Farm, Ottawa, Can., likewise secured excellent results by applying a fertilizer in dry form. A discussion of his work is of interest.

"The first plant employed for conducting a study of this method of cultivation was the chrysanthemum. Sand-culture studies in pots had provided us with a nutrient solution capable of promoting excellent vigor and flower production without causing any burning or disfigurement of the foliage. The varieties Marie Adelaide and Sir William Clark were grown in beds in river sand, planted by 10 by 10 inches. Before transplanting in sand most of the soil was removed from the roots. During the early stages of growth nutrient solution was applied at the rate of ¾ pint per plant, or approximately 1 gallon per square yard, once a week. As growth increased, applications were increased to 1½ pints of solution per plant, or approximately 2 gallons of solutions per square yard, once a week. In addition to the nutrients the plants received water when necessary, thus not requiring any greater increase in attention in this regard than soil plots. The regular waterings were supplemented every 2 weeks by a thorough drenching in order to prevent the accumulation of an excess of salts with consequent injury to the roots. The frequency of application was regulated to some extent by weather conditions, applications being made less frequently during dull cloudy weather or in short day periods.

"*Preparation of the Nutrient Solution.* The following amounts of salts were employed to make up 50 gallons of solution:

Magnesium sulphate..	247.2 g.,	or approximately 8.7 oz.
Potassium phosphate (monobasic).......	134.5 g.,	or approximately 4.75 oz.
Calcium chloride.....	275 g.,	or approximately 9.7 oz.
Potassium nitrate....	300.6 g.,	or approximately 10.5 oz.
Ammonium nitrate...	675 g.,	or approximately 23.75 oz.
Ferric chloride.......	2.5 g.,	(Or the iron may be added separately if the plants indicate the necessity by a yellowing of the foliage. A few drops of 1 per cent solution of ferric chloride used when watering would supply ample amounts)

"Plants grown by this method were strong and vigorous with excellent flower production and free from foliage mottling and burning—often a trouble with soil-grown plants. Plants grown by this method were more easily controlled in their rate of growth than those grown in soil because the applied nutrients were more quickly available.

"From a practical or commercial standpoint it was considered that the use of nutrients in solid form might have more appeal, so a trial was initiated using salts in the solid form and employing sand as a spreader. It was also thought better to employ ordinary commercial fertilizers supplemented by magnesium and iron. Nutrients applied in the solid form are less quickly available to the plant than when applied in solution, so that a time lag may be expected before these fertilizers, especially phosphorus and potassium, would be available. For this reason, an application of salts is made some 10 days to 2 weeks before the plants are set in the bed. During this period the sand is kept moist but not watered to such an extent that leaching of the salts would occur. As in the previous trial, most of the soil is removed from the roots of the plants before transplanting in sand. After the plants are set out, applications of fertilizer are made every 3 weeks at the rate of 1 ounce per 2 square yards. This amount and frequency of application proved very suitable with this lot of plants but could be varied at the discretion of the grower according to plant growth influenced by climatic factors. Watering is given when necessary and is also supplemented by a thorough drenching or leaching before each application of fertilizer to ensure that toxic concentrations of salts do not occur.

FERTILIZER FORMULA

(To be made up with approximately 25 pounds of fertilizer)

Ammonium nitrate...	11 lb. 14 oz., (or 19 lb. 13 oz. of ammonium sulphate)
Magnesium sulphate..	5 lb.
Muriate of potash....	4 lb. 14 oz.
Superphosphate (16%)	3 lb. 3 oz.

"A few drops of a 1 per cent solution of ferric chloride used occasionally when watering will provide all the iron required.

"Bush chrysanthemums grown in this manner proved entirely satisfactory. Good vigorous plants resulted, free from foliage burning or disfigurement, producing an average of 41 blooms per plant.'

The Cultivation of Carnations in Sand[1]

"The use of sand for growing carnations has many good features. It does away with the trouble and difficulty of preparing soil and enables the grower to employ a specific fertilizer program with the assurance that the same results could be expected in successive crops, not having to contend with the varied fertility of soils. The moisture supply is easily controlled; drainage and aeration are good.

"Plants may be grown in sand from rooted cuttings, but it is usually better to grow the plants in the field during the summer months, bringing them into the greenhouse in late summer. The plants are immediately benched in clean, moist sand, spaced 10 by 10 inches.

"If a nutrient solution is used, applications should be made weekly at the rate of ⅓ pint per plant, or ½ gallon per square yard. In addition, the plants are watered as necessary and leached every 3 or 4 weeks.

"*Preparation of the Nutrient Solution.* The following amounts of salts are dissolved in 50 gallons of water:

Magnesium sulphate	247.2 g., or	8.7 oz.
Potassium phosphate (monobasic)	134.5 g., or	4.75 oz.
Calcium chloride	275 g., or	9.7 oz.
Ammonium nitrate	576 g., or	20.3 oz.
Ammonium phosphate (monobasic)	232 g., or	8.1 oz.
Boric acid	1.5 g., or	0.05 oz.
Manganese sulphate	0.25 g., or	trace

[1] Hill, O., and W. Ferguson.

"Carnations may also be grown in sand using ordinary commercial fertilizers in the dry or solid form. Applications are made every 3 weeks at the rate of ½ ounce per square yard.

FERTILIZER FORMULA

(For approximately 25 pounds of fertilizer)

Ammonium sulphate	9 lb. 12 oz.
Magnesium sulphate (Epsom salts)	5 lb. 11 oz.
Muriate of potash	1 lb. 15 oz.
Superphosphate (16%)	7 lb. 8 oz.

"These ingredients should be finely ground and thoroughly mixed. Spread this mixture out in a thin layer. Add to this mixture the following:

Manganese sulphate	1/10 oz.
Boric acid	1 oz.

"These last two substances should be mixed in thoroughly with the previous mixture.

"In addition, make up two stock solutions as:

A. Ferric chloride	¼ oz. in 1 qt. water
B. Calcium chloride	3 oz. in 1 qt. water

"For each square yard of bed put ¼ fluid ounce of solution *A* and 1 fluid ounce of solution *B* in 2 to 3 quarts of water, and sprinkle on the surface of sand at each feeding.

"Plants grown by these methods were healthy and vigorous with excellent flower production and quality and long, sturdy stalks. With the variety Red Laddie, a low-yielding variety, the average number of bloom produced during 1936–1937 was 16 to 18, the length of stem 34 to 38 inches, and the diameter of bloom 3 to 4 inches.

"Where sand may be procured readily and cheaply, the sand method offers distinct possibilities on a commercial basis. The grower has a much greater control over the growth conditions of the plant; insect pests and fungous diseases appear to be more easily controlled; and the same sand can be used for successive crops. The quality of the crop is equal or superior to soil-grown plants, and the cost of production is not increased."

Biekart and Connors grew carnations very successfully for a number of years using sand. They constructed benches so that the drainage slits were covered with short sections of porous tiles to prevent the sand from washing through. The fertilizer was applied in liquid form from a tank located above the benches and connected with the water supply. The installation had a system of by-passes which enabled the operator to apply the solution by means of a hose and later to flush the benches with clear water. The nutrient solution used consisted of

To 185 Gallons of Water	Grams
Ammonium sulphate	112
Potassium phosphate (monobasic)	210
Magnesium sulphate	420
Calcium nitrate	1,800

To avoid precipitation of calcium sulphate, the calcium nitrate and magnesium sulphate were dissolved separately in small amounts of water and then added to the tank. Their results showed that the production of carnations with this method was equal to that with soil and the quality of the flowers equally good.

Sweet Pea

With the sweet pea, it has been found possible successfully to start this crop earlier in the fall than in most soils, without the seedlings' "burning up" or becoming hard. When the greenhouse is very hot, use a nutrient solution about one-half the strength indicated above. With this low concentration the plant is able to take up sufficient water to offset the tremendous evaporation from the leaves at that period of the year. Later on in the fall, the solution may be increased to the original strength, in order to supply more plant foods and to reduce the softness of the tissue. As the bud-drop season approaches, the solution concentration should be doubled again. This practice, if handled correctly, reduces the bud drop to a negligible factor. It must be remembered that as one increases the concentration of the chemicals, one must flush more frequently to avoid harmful residues. It must also be remembered that if the sand used contains a large amount of fine material, both processes just described will either be prevented or greatly slowed up in action. It is quite understandable that a lack of such fine material will increase the immediate danger of injury through the sudden concentration of chemicals if the sand should dry out. This is the reason why some users of sand culture add 3 pounds of colloidal rock phosphate to each 10 cubic feet of sand, to increase the safety factor by increasing this buffer action. Other growers add peat moss at the rate of one-fifth, by volume, to the sand. This will also increase the buffer action. However, both these methods decrease the degree of control that the grower has over his nutrient supply in the sand.

In spite of these results, Biekart and Connors were no more successful in inducing growers to adopt the method than we were. Of course now, with the newer developments of automatic mechanical equipment for applying the nutrient solutions, the use of sand as a medium for the growth of plants commercially has less significance unless the interest shown by many in the growing of plants without soil manifests itself to such a degree as to break down the prejudices against the commercial use of sand cultures. In one particular case a very satisfactory use has been made of it. A grower of chrysanthemum cuttings on a large scale was faced with the alternative of allowing his greenhouse space to be wasted from July to December, during which period no cuttings are inserted in sand, or removing the propagating sand and substituting soil—an expensive operation. Upon suggestion, the grower in question used these propagation benches, filled with a mixture of peat and sand for the maturing of chrysanthemums, sweet peas, Euphorbia, and other crops, by the application of nutrient solutions directly to the medium. Upon the removal of the crops the medium was steam sterilized and again used for propagating purposes.

Growing Seedlings in Sand

The growing of seedlings in sand has much to recommend it. Commercially or in the home the sowing of seed in soil is always attended by troubles of various sorts. The soil may contain parasitic organisms such as cause "damping off." It may be difficult to water. The nutritional balance may be wrong. A crust may form and prevent the emergence of delicate seedlings. The aeration of the soil may be inadequate. All these factors speak in favor of using sand as a medium for starting plants from seed.

Sharp, coarse sand, free of organic matter, should be used. To make sure of its sterility the sand may be sterilized with steam, or boiling water may be poured through it. Or it may be treated with such disinfectants as potassium permanganate (1 ounce to a gallon); formaldehyde (1 part to 50); or chloropicrin. If either of the last two is used, thorough airing of the sand is essential before seed is sown (2 days for formaldehyde and 7 days for chloropicrin).

Commercially, flats or seed pans are the best containers, with some provision at the bottom to prevent the sand from sifting through. Since the sand so used contains no nutrients, additions of these have to be made, in spite of the fact that many large seeds may contain enough stored food to produce seedlings for early transplanting.

Dunlap[1] recommends a solution made of 1 level teaspoonful of saltpeter (potassium nitrate) and 1 of superphosphate (preferably monocalcium phosphate) to 1 gallon of water. We have used 15-30-15 (Nitrophoska) at the rate of 1 ounce to 2 gallons of water with satisfactory results. Still better is the WP formula advocated for "gravel culture" (see Chap. VIII).

Seed may be sown in the conventional manner, in rows or broadcast, after firming the sand and saturating it with nutrient solutions or liquid fertilizer. Usually the one application will suffice for the development of seedlings to the stage of transplanting; but, if necessary, additional nutrient solutions may be added after the seedlings are up. To make sure that no burning of the foliage occurs, a light syringing or sprinkling with water may be made after the application of the solution.

Plants that have a tendency to spindle in the sand may be started without any fertilizer additions, this being applied about 10 days after the emergence of the cotyledons. In that way stocky plants will be obtained. The general culture should be the same as for plants started in soil. Light, humidity, and proper temperatures should be maintained. The seedlings grown in sand may be transplanted to soil, to other sand beds, or into gravel or water for further development. Such seedlings as a rule will have a very satisfactory root system.

Growing of seedlings in cold frames and hotbeds in sand is to be recommended, using the same procedure

[1] *Connecticut Agricultural Experiment Station Circular* 129.

as in flats, except that the bottom of the frame should be lined with building paper bearing no tar. A depth of 6 to 8 inches of sand may be used. Since such seedlings will remain in the sand for a considerable time, a complete nutrient solution is best, used about once a week. Dunlap recommends a solution made as follows:

Per 5 Gallons of Water	Grams
Potassium phosphate (monobasic)	6
Calcium nitrate	20
Magnesium sulphate	10.5
Ammonium sulphate	1.8

The WP solution (Chap. VIII) will produce results just as satisfactory.

Chapter VII

COMMERCIAL GROWING OF PLANTS IN WATER

THE factors that determine the growth of plants in soil are the same for any substitute used—in this case water. Obviously the nutrient solutions act only as substitutes for the nutrients in soil and cannot compensate for the lack of light, temperature, and proper aeration. In other words, in spite of the publicity to the contrary, this method is not a panacea for unfavorable conditions, nor is it a miracle. Furthermore, the yields that are obtained in small containers are not accurate as "yardsticks" for those to be expected from large areas, so that the extravagant claims made in the matter of increased production are highly exaggerated. Comparisons between yields of tomatoes in the greenhouse and those grown directly out of doors are unfair, since it is a well-known fact that greenhouse-grown tomatoes, grown in soil, with special supports, training, pruning, and culture outyield the outdoor crops. No convincing evidence has yet been presented where, on a large-scale production in the greenhouse, crops grown side by side, one group in water and the other in soil, differed greatly in yields. Furthermore, since the nutrients supplied are similar to those from soil, there is no justification for the claims that better quality of product may be secured. In general it must be remembered that successful production of crops in soil is a guide in the growth of plants in nutrient solutions. The same factors obtain, and the same troubles develop, together with a few that we never thought of in soil culture.

It is conceivable that under favorable climatic conditions, with a cheap source of water, crops may profitably be grown directly outdoors without soil, provided their selection and selling price will compensate for the initial investment in the system. In the greenhouses, however, where artificial conditions already obtain, and where additional costs for equipment may be balanced by the reduction of labor over a period of years, the future possibilities of soilless culture are much greater. For that reason we are confining the discussion of water culture in this chapter to commercial greenhouse installations. The principles involved, however, apply equally to amateur practice.

Although the author's personal leanings are toward the modified method called "gravel culture," there are some possibilities in growing crops in water. In our estimation the only advantage to be derived from such a method is the availability of a large volume of solution, which may be useful during the hot summer season in compensating for a high transpiration rate.

In the greenhouse the regulation-sized benches, 36 to 42 inches in width, 6 to 8 inches deep, and any desired length, may be used. These benches, or tanks, must be waterproofed, using asphalt (not tar) with a melting point of about 190°. It may be applied with a mop. Concrete or metal may be substituted for wood, but these materials should be thoroughly coated to reduce to a minimum the giving off of toxic substances. Provisions have to be made for the introduction of water and solutions to the tanks and likewise for their removal whenever necessary.

The seedlings may be started in sand (Chap. VI) and then transferred to the water tanks or started directly on trays in the tanks. Trays, fitted into the tanks, are made of wood with a bottom of screening with a mesh of about ¼ inch. On top of this are placed excelsior, shavings, or moss. The young plants are set into holes made in these trays with roots suspended below in the solution, which at the beginning is kept level with the screen. As roots develop, the level of the water is dropped so that approximately 2 inches of air space is maintained between the solution and the screen. As the plants grow they have to be supported by stakes or strings attached to overhead wires.

Since water does not retain enough free oxygen, some provision has to be made for aerating the medium; otherwise respiration will not take place, and roots will die. Alexander, Morris, and Young[1] suggest the following methods for aeration:

"The most simple method makes use of a centrifugal circulating pump and motor operated continuously.

[1] *Ohio Agricultural Experiment Station Special Circular* 56.

The solution is kept in motion by attaching the inlet of the pump to one end of the culture tank and the outlet to the other. In order to aerate at the same time the solution is circulated, an air valve is placed on the inlet and so adjusted that the pump takes in both air and water. The air thus taken in is thoroughly mixed with the water by the impeller of the pump.

"With the other method of aeration, air is bubbled through the solution in the culture tank. The air is supplied by a motor-driven rotary air pump operated automatically by a time clock. Probably the amount of aeration necessary will vary with different plants and their rate of growth; but for corn and tomatoes growing outdoors in the summer, air is bubbled through the solution 15 minutes of every hour during the day. During the night there are only four 15-minute periods of aeration. A piece of ⅜-inch pipe capped on one end, with ¼-inch holes drilled every foot, serves as an aerator. The pipe is laid lengthwise in the bottom of the tank and is connected to the air line by means of a rubber hose."

The same workers recommend the nutrient solution for tomatoes as shown in Table IV.

In addition to the factor of aeration, iron is one of the elements that is difficult to keep in solution. It precipitates out and must be replaced. Ferrous sulphate added at 1 p.p.m. is most satisfactory. This may have to be done daily.

In water culture the pH of the solution for tomatoes should be about 5.5. It should be checked at least twice

TABLE IV
Suggested Nutrient Solution

Fertilizer salts*	Molecular concen-tration	Grains for 10 gallons of solution	Grams for 10 gallons of solution	Ounces for 10 gallons of solution
Potassium nitrate, KNO_3	0.006	354	23	0.8
{ Calcium nitrate, $Ca(NO_3)_2$	0.008	770	50	1.8
or				
{ Calcium sulphate, $CaSO_4 \cdot 2H_2O$ (gypsum)	0.008	770	50	1.8
Magnesium sulphate, $MgSO_4 \cdot 7H_2O$ (Epsom salts)	0.0015	231	15	0.6
{ Potassium phosphate, KH_2PO_4	0.001	77	5	0.2
or				
{ Calcium phosphate, $CaH_4(PO_4)_2 \cdot 2H_2O$	0.0005	77	5	0.2
Ammonium sulphate, $(NH_4)_2SO_4$	0.0005	38	2.5	0.1
{ Ferrous sulphate, $FeSO_4 \cdot 7H_2O$	¼ liquid oz. (7 cc.) of stock solution = ½ p.p.m.			
or				
{ Ferric ammonium citrate	¼ liquid oz. (7 cc.) of stock solution = ½ p.p.m.			
Boric acid, H_3BO_3	¼ liquid oz. (7 cc.) of stock solution = ½ p.p.m.			

* See footnote on facing page.

a week, since too great a fluctuation will cause uneven growth by precipitating some of the elements out of solution. The method of checking the reaction and the materials used for acidification and neutralization are discussed in Chap. VIII.

Alexander, Morris, and Young make the following statement relative to the concentration of solutions: "To regulate the amount of water available to plants grown by the water method it is necessary to vary the concentration of the nutrient solution. It should be remembered that with a high concentration of salts in the solution, less water is available to the plants; and that with a lower concentration, more water is available. During late spring, summer, and early fall, the concentration of the solution should be as indicated in the table. For early spring and late fall the concentration should be doubled; *i.e.*, twice the indicated

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* "Better results may be secured by using one-half the amount of ammonium sulphate during the dark winter months and the hot summer months.

"To make stock solution of ferrous sulphate dissolve ½ ounce of ferrous sulphate in 1 quart of water to which 5 drops of sulphuric acid have been added.

"To make stock solution of ferric ammonium citrate dissolve ⅔ ounce of ferric ammonium citrate crystals in 1 quart of water. Store in dark.

"To make stock solution of boric acid dissolve ½ ounce of boric acid crystals in 1 quart of water.

"To make stock solution of sulphuric acid add 2 liquid ounces of acid to 2 quarts of water. (Important: Add acid to water, using enamel pan.)

"To make stock solution of potassium hydroxide dissolve 4 ounces of potassium hydroxide in 2 quarts of water. (Note: The water gets hot; use enamel pan.)

"To make stock solution of ammonium sulphate dissolve 9½ ounces of ammonium sulphate in 2 quarts of water."

amounts of chemicals should be used; and during the dark weather of the winter months, three times the amounts of chemicals should be used."

Solutions should be changed entirely every 3 or 4 weeks, and in the interim tests made to determine the state of concentration of the various elements present.

Many difficulties will present themselves in the process of growing plants in water. Among the most serious will be the maintenance of the proper pH, the retention of iron in solution, the upkeep of the necessary aeration, the regulation of solutions at proper levels of concentration, the control of pests, and the possibility of the spread of fungous and bacterial diseases. Constant watchfulness, thorough checking of details, and keen observation, together with fundamental information concerning plant growth, are all necessary for the success of such a venture.

Chapter VIII

COMMERCIAL GROWING OF CROPS IN GRAVEL

IN COMMERCIAL greenhouses devoted to the production of cut flowers, the use of nutrient solutions in gravel has definite possibilities. (The term "gravel" is used generically and includes any inert medium that conforms to certain specifications.) In spite of the ability of many growers to produce excellent crops in soil, the nonuniformity of this medium makes standardized practices impossible. As a consequence, troubles arise that are frequently difficult to analyze. And even if the diagnosis is correct, remedial measures often are inadequate.

To the advantage of using a constantly uniform growing medium many others may be added. The cost of production in recent years has been out of proportion to the selling price of the products. This has been due largely to the cost ratio of the hand labor involved. Although the actual labor cost has not increased, the selling price has been reduced materially. In gravel culture fully 50 to 75 per cent of hand labor is eliminated, because watering and fertilizing are done mechanically, and weeding and cultivating are practically eliminated. Labor in greenhouses employing the usual methods constitutes almost one-half of total cost of production.

Furthermore, the changing of soil as usually practiced—an expensive operation—is completely eliminated. Still another advantage lies in the fact that the type of growth desired may be readily controlled by the manipulation of solution concentrations, variation of nutritional constituents, and the frequency of applying solutions. Where soil is used such manipulation is difficult because of the many factors involved.

The advantage often claimed for sand or gravel culture—that of increased production—can easily be overstressed. There has been some evidence of increased production with roses and sweet peas and some other crops, but too little time has elapsed since the inception of this method to warrant much exuberance on this point. Likewise, the claim of better quality may be disregarded for the time being, although experimentally our results justify the statement that better than average quality may reasonably be expected.

Some growers have become very enthusiastic about the results secured after one or two seasons' trials and have been outspoken in favor of growing crops in gravel. However, in spite of our own successes experimentally, we are still cautious about advising large-scale attempts until such time as all the present difficulties are eliminated and the majority of problems solved. New and unexpected troubles develop constantly, and in inexperienced hands these may lead to the loss of entire crops. We do feel, however, that any grower with a fair knowledge of the fundamentals of plant growth in soil and willing to use patience and painstaking effort is in a position at present to

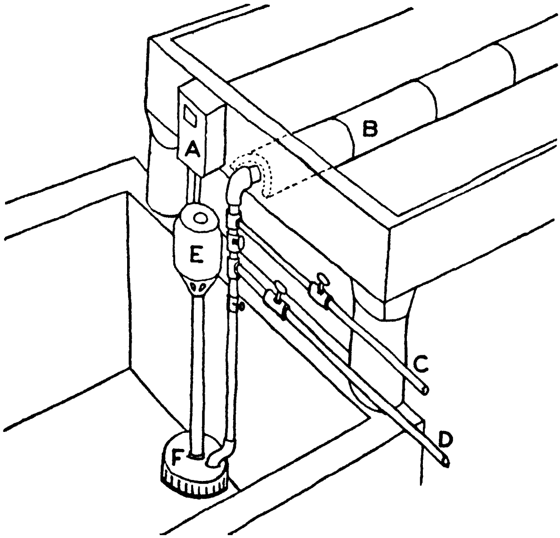

FIG. 8.—Flat-bottomed subirrigation bench. *A*, time switch; *B*, half tile or trough; *C*, connection with water supply; *D*, connection for drainage of tank; *E*, motor; *F*, sump pump.

devote a small area to this method with expectations of success. The present uncertainty of the best mechanical equipment is likewise a serious drawback in large-scale operations.

Construction of Benches (Figs. 8 and 9)

The best bench is one of concrete, perfectly waterproofed, with 6-inch sides and an approximate slope of 1 inch to 100 feet. The "V-type" bench, using a

4-inch half tile along the center, is more satisfactory than the flat-bottom bench, largely because of quicker drainage of the solution to the tank below.

Wooden benches, properly waterproofed and adequately supported to hold without sagging the weight

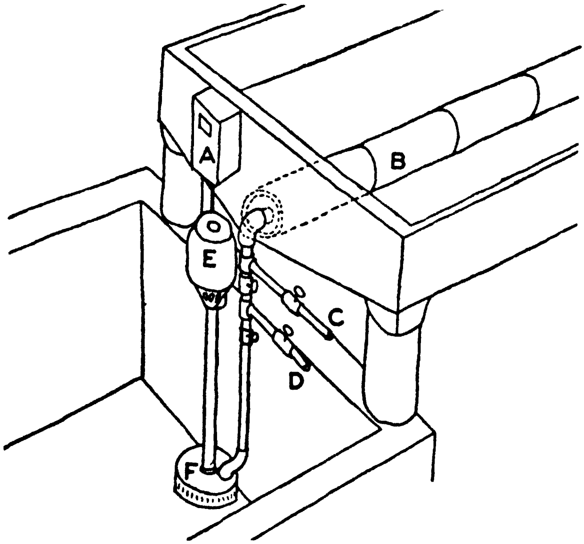

FIG. 9.—V-type subirrigation bench. *A*, time switch; *B*, 4-inch porous tile; *C*, connection with water supply; *D*, connection for drainage of tank; *E*, motor; *F*, sump pump.

of the medium used, are satisfactory, but they must be well constructed and rigid.

If one is starting with a new bench, concrete is the easiest to waterproof. In the case of a wooden bench, the cracks in the bottom may be covered with lath, and the bottom edges inside reinforced with strips of quarter-round molding. The strip is merely tacked on to the base and eliminates the large right-angle corner that forms the weakest part in a bench of this type. Next, the sides and bottom of the bench are covered with heavy asphalt roofing paper. Lastly the entire covering of asphalt paper is coated with a heavy coat of pure emulsified asphalt.

Recent findings indicate that solutions standing in the bottom of the bench are definitely detrimental to proper root action. As little as ⅛ inch of liquid standing constantly under the plants of roses and chrysanthemums has caused serious trouble. Because of that, flat-bottom benches should have a modified V to make sure of the elimination of all liquids from the bench.

Tars and oils are very toxic to plants, so that it is important to use a *pure asphalt.* Emulsified asphalts containing no oils should be brushed on, first using a thin watery emulsion. Three coats should be given. High-melting-point asphalts, formerly recommended, are objectionable because of cracking due to their brittle nature.

The nutrients are supplied from the bottom of the bench by means of a centrifugal or sump pump connected to a cistern which is placed at a lower level than the bench. The pump is operated by a time clock which pumps the solution into the benches as many times each day as desired. The solution is allowed to come up within an inch of the top surface of the gravel, the height being governed by the amount of solution kept in the cistern.

When the proper amount of solution has been pumped in, the pump is turned off automatically, and the solution drains back by gravity into the cistern. The solution enters one end of the bench by means of a short nipple. It flows the entire length of the bench, which may be a distance of 100 feet, through an inverted 4-inch roofing gutter or a wooden trough thoroughly coated with asphalt or half tile.

The inflow pipe should be 1 inch in diameter and preferably enter the bench at the end. (Galvanized connections are avoided wherever possible because of zinc damage.) This pipe should enter the trough placed in the middle of the bench. This trough should be 4 inches and may be galvanized or made of wood or half tile. If galvanized, every precaution should be taken to cover the galvanizing with asphalt and prevent possible damage from zinc. Beads on inverted-eaves trough should be cut off, since it is difficult to make proper coverage with asphalt. Be sure that the trough is set so that perfect contact between it and the bench is *not* made. Placement of wedges impervious to water underneath the trough is desirable to allow for free passage of water from the trough to the surrounding medium. In larger installations solutions may be pumped through several openings spaced evenly along the bench.

The tanks should be completely waterproofed, made of concrete or any material that will hold water and yet will not give off any undesirable materials. For safety, all tanks should be coated with asphalt. The size of the tank is figured on the basis of the total volume of the bench, allowing approximately 40 per cent of the total for the solution. Thus a bench 100 feet long, 4 feet wide, and 6 inches deep will require a tank of about 80 cubic feet capacity. In large tanks mechanical agitators are sometimes used.

Pumps (Fig. 10)

Either a sump or a centrifugal pump may be used. The sump pumps are easier to install, and no separate compartment is required in the tank to keep the motor dry. Usually no more than 30 minutes should be required to pump the nutrient solution into a bench 100 feet long. About 60 minutes will be required for it to drain back into the tank. The quicker the drainage the better, since unnecessary retention of water about the roots may cause damage. We have tried the following pumps and found them satisfactory:

Deming #4000-M, No. 1 *Side Suction Centrifugal Pump.* (When ordering, specify that a grease cup be supplied at the main bearing instead of the standard water-lubricated mechanism. Capacity 30 gallons per minute, 10-foot head.

Deming #4602, Sump Pump. Prices vary according to height of pump desired. Capacity 40 gallons per minute, 10-foot head.

Gould "Cid" Sump Pump, No. 3151. Gould's Pumps, Inc., Seneca Falls, N. Y.

Myers No. 6101 *Sump Pump.* Capacity 25 gallons per minute, 10-foot head. F. E. Myers & Bro. Co., Ashland, Ohio.

Three valves can be located in the system so that when it is desired to change solutions, the valves to the bench can be closed and another valve opened to expel the old solution into a drain. Centrifugal pumps must be placed below the surface of the water so that they will be primed at all times.

Clocks

Whether or not this automatic feature will be desired depends upon the operator's own judgment. Actually it is a safeguard and insures regular pumpings. Since we have not yet reached that fine stage of development that enables us to determine exactly when to pump, the present empirical recommendations of so many times a day serve the purpose. The following clocks are available:

Type T-27 Time Switch, Single-pole, Single-throw, General Electric Co., Schenectady, N. Y. (Specify if 115 or 230 volts is desired.) Any number of additional "on" and "off" tabs can be secured.

Type K-11 Sangamo Time Switch, Sangamo Electric Co., Springfield, Ill., is satisfactory if a maximum of three pumpings per day is desirable.

GROWING MEDIA

The most satisfactory material for the growth of plants with the subirrigation method is one that is inert, does not give off any undesirable elements, does not change the pH, retains a sufficiency of water, and does not disintegrate. To date we have found nothing that approximates this ideal so closely as "Haydite," although other materials (such as traprock) may be equally suitable. The "C Media" size of Haydite (Hydraulic-Press Brick Co., South Park, Ohio) is best. In spite of opinions to the contrary, the cost of Haydite is no greater than that of cinders when the latter are properly prepared. Furthermore, its uniformity permits of comparable recommendations over a wide territory.

Cinders, which have been widely recommended as a growing medium, should be used with caution. They vary with the coal from which they come. They disintegrate readily. Their water-holding capacity is high (too high unless used with caution). They contain toxic substances (boron has already been shown to be present in toxic amounts). They have to be leached before use. They frequently are alkaline and precipitate phosphorus and iron. If used, the size should run ½ to ¾ inch.

Gravel has been advocated, but its value should be weighed on the basis of crop used. In other words, calcareous (lime-bearing) gravels are useful for plants that will grow in pH of 7 or over. As a consequence of high pH, precipitation of iron and phosphorus frequently occurs. In some cases deficiency of boron has been observed. Acid gravels (silica) are not easily obtainable and tend to lower the pH too much. Like the calcareous types, they are very heavy to handle. Where wooden benches are used for gravel they require strong supports.

Limestone chips may be used under conditions similar to those required for calcareous gravel. All gravels should run ¼ to ¾ inch in size.

Slag from blast furnaces is dangerous. It is alkaline and may contain gases causing irreparable damage.

SOLUTIONS

Many different formulae have been advocated by different workers. The differences are not very great. To save confusion we present here a solution that has proved satisfactory on many crops in our experiments.

COMPOSITION OF THE WP FORMULA

Chemicals	For Each 1,000 Gallons of Water
Potassium nitrate	5 lb. 13 oz.
Ammonium sulphate	15½ oz.
Magnesium sulphate	4 lb. 8 oz.
Monocalcium phosphate*	2 lb. 6 oz.
Calcium sulphate	10 lb. 11 oz.
Total	24 lb. 5½ oz.

* The monocalcium phosphate should be "food grade," since it is desirable that the fluorine content be low. Monsanto Chemical Co., St. Louis, Mo., carries a food-grade phosphate of very low fluorine content.

The amounts of chemicals given in the foregoing formula should be mixed together in dry form. The mixture will not deteriorate but can be stored and used as needed.

A single-strength WP solution should be used for the first month on all newly planted crops. (This same solution is best for all types of bulbs or corms during their entire period of growth.) When the plants have become well established, the concentration is doubled, which means that twice the amount of chemicals recommended in the WP solution should be used.

To all solutions add manganese sulphate. Dissolve 1 ounce of manganese sulphate in 1 gallon of water. Use 2 quarts of this solution to 1,000 gallons of complete solution. Iron should be added regularly, in the form of ferrous sulphate at the rate of 4 ounces to 1,000 gallons. The frequency depends upon tests for iron.

ANALYSIS OF 2 WP SOLUTION

	Parts per Million
NO_3 (from potassium nitrate)	800
NH_3 (from ammonium sulphate)	56
Total nitrogen translated to NO_3	1,000
(56 p.p.m. of NH_3 is equivalent to 200 p.p.m. of NO_3, on a basis of equal amounts of nitrogen)	
PO_4	400
K	500
Ca	600
Mg	100

Most of the chemicals used are of a commercial grade. They include:

	Cost, Cents per Pound	
KNO_3, potassium nitrate	3	
$(NH_4)_2SO_4$, ammonium sulphate	2½	
$MgSO_4 \cdot 7H_2O$, magnesium sulphate	2½	
$CaH_4(PO_4)_2 \cdot H_2O$, monocalcium phosphate	8	(food grade)
$CaSO_4 \cdot 2H_2O$, calcium sulphate	1½	

Sources of Chemicals

Potassium nitrate: F. W. Berk & Co., 420 Lexington Ave., N. Y. C.

Monocalcium phosphate: Monsanto Chemical Co., St. Louis, Mo., and Akron, Ohio. (Also Cincinnati and Cleveland, Ohio.) (Food grade, 0-55-0.) This has a very low fluorine content.

Ammonium sulphate, calcium sulphate, magnesium sulphate, manganese sulphate, ferrous sulphate may be obtained from local dealers.

In view of the fact that the materials used are not chemically pure, they contain the necessary trace elements except those mentioned. Recommendations for adding boron, zinc, copper, *et al.* should not be followed without specific advice. Considerable damage has resulted in some cases because of overzealousness.

Purdue Solution

Withrow and Biebel[1] advocate a somewhat different solution from the one recommended by us. In many cases it has proved very satisfactory.

Solution 2D is a good all-round solution which can be compounded as a complete mixed fertilizer and dissolved in water in the proportions given. This element of convenience in solution 2D may compensate for the fact that it is not quite so good as the "E" series of solutions. It is especially convenient for

[1] *Purdue University Agricultural Experiment Station Circular* 232.

TABLE V

NUTRIENT SOLUTION FORMULAE

Number	Salt (fertilizer-grade chemicals)	Amounts per 1,000 gallons water	
		Pounds	Ounces
2D	Magnesium sulphate (anhydrous).......	..	9
	Monocalcium phosphate (treble superphosphate, 0-48-0).................	1	6
	Potassium nitrate (13-0-44)............	9	12
	Calcium sulphate (agricultural gypsum)..	6	10
	Ammonium sulphate (20-0-0)..........	1	4
	Total mixed fertilizer per 1,000 gal. water....	19	9
	Ounces per gallon water, 1/3		
	Teaspoons per gallon water, 2		
1E	Magnesium sulphate (anhydrous).......	4	10
	Monocalcium phosphate (treble superphosphate, 0-48-0).................	5	8
	Potassium nitrate (13-0-44)............	5	14
	Calcium nitrate (15.5-0-0).............	6	6
	Ammonium sulphate (20-0-0)..........	..	10
2E	Magnesium sulphate (anhydrous).......	..	9
	Monocalcium phosphate (treble superphosphate, 0-48-0).................	1	6
	Potassium nitrate (13-0-44)............	5	14
	Calcium nitrate (15.5-0-0).............	6	6
	Ammonium nitrate (35-0-0)....... .	1	7

Microelement Supplement

Salt	Ounces per 1,000 gallons solution
Ferrous sulphate (copperas)......................	4
Manganese sulphate............................	1/8
Copper sulphate (blue vitriol)....................	1/32
Zinc sulphate (zinc vitriol)......................	1/32
Boric acid..................................	1/4

preparing small quantities of solutions for watering seedlings and the growing of house plants.

The nutrient solutions 1E and 2E are best prepared by dissolving the fertilizer chemicals individually in small quantities of water before adding to the cistern of water.

Solution 1E is a good solution for winter production when it is desirable to maintain a slow rate of nitrogen assimilation. Sufficient ammonium sulphate is present to keep the solution from becoming too alkaline. Solution 2E will promote a more succulent type of growth and is better suited to spring, summer, and fall conditions than 1E. With this solution, the ammonium nitrate concentration should be varied from 2 to 8 millimolar concentration depending upon sunlight conditions and the type of growth desired. If the rooting medium is high in lime, a more stable pH is maintained if equivalent molar quantities of ammonium sulphate are substituted. Ammonium sulphate promotes a more acid reaction than ammonium nitrate under most conditions.

Changing Solutions

Pay no attention to the recommendation that solutions be changed once a week or to the one that recommends no change at all. Once a week is wasteful; and never changing results in the possibility of accumulations of toxic compounds which have been known to cause trouble and stunting. After many trials we feel that a complete change of the solutions should be

TABLE VI

Commercial Fertilizers as Nutrient Solution Salts

Nitrogen salts	N, per cent	Purity, per cent	Grams per mole
Ammonium sulphate, $(NH_4)_2SO_4$	20	94	140
Monoammonium phosphate, $(NH_4H_2PO_4)$-(Ammo-phos A)	11	85	150
Ammonium nitrate, NH_4NO_3	35	98	80
Sodium nitrate, $NaNO_3$	16	97	90
Potassium nitrate, KNO_3	13	93	110
Calcium nitrate, $Ca(NO_3)_2$	15.5	90	180
Phosphate sources	P_2O_5, per cent		
Treble superphosphate, $CaH_4(PO_4)_2$	45	75	320
(food grade)	55	92	272.38
Monoammonium phosphate, $(NH_4H_2PO_4)$-(Ammo-phos A)	48	85	150
Phosphoric acid, H_3PO_4 (syrupy)	83	90	110
Potassium salts	K_2O, per cent		
Potassium nitrate, KNO_3	43	93	110
Potassium sulphate, K_2SO_4	48	89	200
Potassium magnesium sulphate, $K_2SO_4 \cdot MgSO_4$	28	85	350
Potassium chloride, KCl (imported)	50	80	95
Potassium chloride, KCl (Trona)	63	98	75
Magnesium salts	MgO, per cent		
Magnesium sulphate, $MgSO_4 \cdot 7H_2O$ (Epsom salts, technical grade)	15	46	260
Potassium magnesium sulphate, $K_2SO_4 \cdot MgSO_4$	12	85	350
Calcium salt	Ca, per cent		
Calcium sulphate, $CaSO_4 \cdot 2H_2O$	23	85	198.03

made once in two months. In the interim, weekly tests will indicate whether proper nutrient levels are being maintained or not. The following levels may be considered safe, even though the original parts per million may have been much higher.

MINIMUM LEVELS REQUIRED

	Parts per Million
Nitrate	500
Phosphate	10 (low level due to precipitation)
Potassium	150
Calcium	250
Magnesium	10
Iron	10
Manganese	5

After the plants begin to grow, the composition of the nutrient solution changes because the constituents are absorbed by plant roots. How rapidly the change occurs depends on the rate of growth of the plants and the volume of solution available for each plant. This absorption of nutrient salts causes not only a decrease in the total amounts of salts available but a qualitative alteration as well, since not all the nutrient elements are absorbed at the same rate.

During the period of growth, it is necessary to keep the tanks filled to a certain level for the proper filling of benches. Considerable loss of solution is encountered daily—some through intake by plants, some through evaporation from the medium. In the interim between complete changes of solution, therefore, it becomes necessary to add water regularly. Additions of the necessary elements to the solution must also be made in order to maintain the correct concentration. Tests of the solution will indicate the additions needed. The levels indicated in the table above may be adhered to, and no attempt made to keep the solutions constantly at their initial concentration.

Acidity or pH Factor

For most crops pH is kept at 6.0 to 6.5. Sweet peas, stocks, snapdragons, gerbera, and a few others may be grown at pH 7 or higher. In spite of notions to the contrary, the success of growing crops in gravel or similar materials depends largely upon the maintenance of a correct pH, all other factors having been taken care of.

To raise the pH, use a stock solution of 2 ounces of potassium or sodium hydroxide to 1 gallon of water. Stir while adding. To lower the pH, use a stock solution of 1 ounce of concentrated sulphuric acid to 1 gallon of water. For large tanks add the hydroxide in flake form, and stir vigorously for several minutes.

Testing Solutions

The Simplex Soil Testing Kit or the LaMotte Soil Testing Kit may be used for general purposes. (Simplex: Edwards Laboratory, Lansing, Mich.; LaMotte: LaMotte Chemical Co., Baltimore, Md.) For accurate tests for nitrogen use the phenoldisulphonic method.

Before taking samples for testing, the solution should be brought to the original volume in the tank. Unless this is done, the tests may be too high because of greater concentration due to reduced volume. *Solutions should not be stirred before sampling, because the deposits at the bottom of the tanks are not available to the plant and may affect the test.* Samples for the phosphorus test should be taken before adding the hydroxide or sulphuric acid to adjust the pH. Quick precipitation of phosphorus is apt to occur. However, after about 48 hours the phosphorus level will return to its original state due to a drop in the pH and the subsequent solvent action.

In testing with the Spurway method, emphasis should be placed on accuracy and the following of directions exactly. The volumes of solution, amounts of reagents, and the time before comparing with standard charts should be observed carefully. Cleanliness of equipment is essential to avoid contamination. Duplicate tests should be run to insure accuracy, since they are dependent upon color comparisons. Persons who are color-blind should delegate the tests to others. Certain reagents lose their strength or may become contaminated and should be watched carefully.

In the making of tests it should be borne in mind that the nutrient solutions are much more concentrated than soil extracts, for which purpose these tests were originally devised. Because of that fact, the colors developed in test tubes are often beyond the range of the color charts provided. To correct this condition it is necessary to dilute the solution samples with distilled water so the color of the sample will come within the range of the color chart. In diluting, a volume of the sample is increased a known number of volumes of distilled water, each equal to the volume of the sample. The diluted sample may then be compared with the chart. Dilutions are made until the developed color matches approximately the deepest color on the chart; then this value is multiplied by the number of dilutions. This figure will represent the concentration of the solution in parts per million. The equipment for dilution consists of a graduated pipette for measuring volumes, three or four graduated cylinders, and several test tubes.

The Spurway test for potassium is not reliable in the presence of 50 p.p.m. of ammonium NH_4 or more. A solution high in ammonium will give the same colored precipitate for both ammonium and potassium. However, the 56 p.p.m. of ammonium present in the 2 WP solution soon changes to the nitrate form which does not interfere with potassium. As a consequence, potassium testing should be deferred for 2 or 3 days after fresh solution is made.

In testing for pH, the volume of the solution likewise must be at the proper level. The Soiltex Kit (Edwards Laboratory) is useful for the purpose. To one drop of the nutrient solution are added three to four drops of the testing fluid.

In general, although the Spurway tests are not so accurate as some others, they are sufficiently accurate for all practical purposes and have the distinct advantage of being simple, easy to perform, and quickly made.

For greater accuracy in testing for nitrates, the phenoldisulphonic acid method is to be preferred to the diphenylamine—the one usually included in the test kits. However, it requires considerable equipment and is time consuming. For those interested, we are presenting the method in detail.

PHENOLDISULPHONIC TEST FOR NITRATE NITROGEN

Making Reagents

Phenoldisulphonic Acid. Heat 15.0 grams of reagent grade white phenol ($C_6H_5{\cdot}OH$) with 100.0 milliliters of concentrated sulphuric acid (H_2SO_4 reagent grade) at 100°C. for 6 hours. Cool and put in a glass-stoppered bottle. This reagent will keep for at least 6 months.

Ammonium Solution. Add one part by volume of 0.90 specific gravity ammonium hydroxide (NH_4OH) to four parts of water. The concentration of this reagent is not critical. Do not keep over several weeks. It may slowly oxidize, forming some nitrates.

Standard Nitrate Solution. Make up a solution of potassium nitrate (KNO_3) by dissolving 10.11 grams of reagent grade potassium nitrate in enough distilled water to make 100.0 milliliters. Pipette 10.0 milliliters of this into a 1-liter volumetric flask, fill to the mark with distilled water, and mix. This is a solution containing 10 milliequivalents of nitrate nitrogen.

Discussion of the Reaction and the Test

Phenoldisulphonic Test. The color developed during the nitrate test is due to the formation of an alkali salt of nitrophenolsulphonic acid. This is a single compound and is quite stable. The amount of this compound formed under the test conditions varies directly as the amount of nitrate present. A narrow range of standards is used because comparison is easier in Nessler tubes and because a smaller amount of sample is needed for evaporation. Also, interfering constituents in the nutrient solution are kept down to a minimum. High percentages of chlorides and carbonates may produce low readings. Chlorides cause a lessening in the intensity of the color. Nitrates may be lost by the release of carbon dioxide from the carbonates when acidified, as the released gas may sweep off part of the nitrates.

The sample should not be heated over 100°C., as too rapid evaporation will cause popping as the sample dries down. High temperatures may also cause some decomposition of the dry residue. For this reason it is preferable to use small porcelain evaporating dishes of about 50-milliliter capacity for evaporating the samples to dryness. By placing the porcelain dish on a 150-milliliter beaker containing boiling water, a water bath is formed. This setup allows the sample to reach temperatures of nearly 100°C. and yet prevents boiling and spattering which result in loss of nitrates, as mentioned previously.

It is imperative that clean, nitrate-free Nessler tubes, evaporating dishes, stirring rods, etc., be used at all times. If a dark brown precipitate develops in the phenoldisulphonic acid reagent at any time, the reagent has become contaminated and should be discarded. This contamination is often caused by using pipettes that have previously come in contact with nitrates.

The best Nessler tube to use is the low form, 100-cubic centimeter type.

Making Permanent Standards

The standards should be made so that the highest concentration is about 1 milliequivalent of nitrate. Ten different concentrations in this range can be detected, but for much work only seven may be needed.

Pipette 10.0 milliliters of the standard potassium nitrate solution into a 50-milliliter beaker on a hot plate, and evaporate to dryness at 100°C. Allow to cool, and pipette 2.0 milliliters of phenoldisulphonic acid into the residue in the beaker, making sure that the acid comes in contact with and dissolves all the residue. Tilt the beaker at intervals for 4 minutes to allow thorough mixing and to make sure that the reaction is entirely complete. The dissolution of the residue can be speeded by using a *clean* solid glass stirring rod to scrape the residue from the sides of the evaporating dish, thereby exposing more surface of the residue to chemical action with the acid. Add 5 to 10 milliliters of water rapidly, being careful to avoid spattering, since the mixture gets very hot. Hold pipette in the ammonium reagent until the deepest yellow color develops. Then add a few drops in excess. This will take about 25 milliliters of ammonium reagent. Now pour into a graduated cylinder, and dilute to 100.0 milliliters with water. Pour into a 125-milliliter Erlenmeyer flask with a rubber stopper for storing, or pour directly into a Nessler tube for comparison. The color fades slightly for the first half hour, and the standard should not be used until at least that old. This standard contains 1 milliequivalent of NO_3.

Make the next standard using 9.0 milliliters of the standard potassium nitrate solution. When completed this will contain 0.9 milliequivalent of NO_3. Make the next using 8.0 milliliters of potassium nitrate, and so forth on down.

The following table shows the approximate parts-per-million relationship between the various permanent standards:

Milliequivalent Standard	Parts per Million
1	62
0.9	55.8
0.8	49.6
0.7	43.4
0.6	37.2
0.5	31.0
0.4	24.8
0.3	18.6
0.2	12.4
0.1	6.2

These standards will not fade for 6 months, provided they are kept in a dark, cool place when not in use. Keep tightly stoppered so that none of the solution evaporates. Care should be taken that none of the solution is lost in transferring from the bottles to Nessler tubes and back again.

Making the Test

The same technique is used in making the test as is used in making the standard, except that the sample should be made slightly alkaline (pH 7.5) with sodium hydroxide before evaporation. Since the range of concentrations of the standards varies from 0.1 to 1 milliequivalent of nitrate, the dilution of the sample should vary—according to the assumed concentration of nitrate in the sample—to bring it within this range. The comparison should be made after ½ hour, since the color fades slightly at first.

Comparison is made in the illuminator (described below) by looking down through the Nessler tubes. A light filter of dark blue glass will facilitate comparison, but higher light intensities must be used.

It is best to have a uniform light source for comparison of the unknown samples with the standards. A small wooden box with dimensions of 6 by 13 by 10 inches has been found satisfactory. Two or three thicknesses of ground glass should be placed over one 6- by 13-inch side for comparison. The ground glass diffuses the light coming from five 60-watt bulbs in a staggered line on the bottom of the box.

Time of Pumping

The number of times the solution is pumped depends upon the medium used and the environmental conditions. It has been found that there is little drop in moisture for 18 hours after pumping. For example:

Medium	Per cent moisture	
	At pumping	18 hours after pumping
Haydite	17	16
Cinders	41	39

Because of this, the media that retain the most moisture should be pumped less frequently. This is especially important when crops are first planted and root action is slow and dependent upon satisfactory aeration. Ordinarily in the winter, pumping once a day is sufficient; in the spring and fall, three or four times a day; and during the summer it may be necessary to pump five times a day. The pumping periods may be best distributed during the day.

Pest Control

Since the media in which plants are grown under this method do not contain any organic matter that would act as a buffer, any spray materials used may cause damage to the roots. *To prevent this damage, the benches should be flooded with clear water while being sprayed.* In no case should this water be allowed to flow back into the solution tank. The use of dusts containing sulphur or other insoluble materials may cause damage. Sulphur definitely drops the pH. Cyanide fumigation is not safe. Nicofume fumigation is safe. The use of copper in solutions for the control of disease should be avoided. Toxicity is apt to result.

The use of certain materials in solutions is being tried under our supervision to immunize plants to attacks by insects. Some promise has been shown, but the results are not conclusive enough yet to warrant recommendations.

Recommendations for Specific Crops

Table VII gives the recommendations for crops from the standpoint of media, solution, and pH.

Rose (Fig. 11). Results with roses experimentally warrant their being tried in gravel. The commercial installations on a large scale to date have been only partially successful, largely because of failure to observe the latest information on the subject. "Started eyes," dormant buds, or grafted or own-root roses may all be used for planting. The first two should be planted as early after January as possible directly from storage. They will start growth almost immediately. If necessary to wait, the plants should be held in storage and not potted and started previous to planting. Own-root roses should be grown outdoors for one season before planting. The grafted plants may either be planted with a ball of soil, or else the soil washed from the roots. Our tests have shown that, contrary to the opinions of others, the ball of soil apparently does

TABLE VII

RECOMMENDATIONS FOR CROPS

Crop	Media	Solution	pH
Rose	Haydite, silica gravel, cinders (with caution)	2 WP (young stock start with WP)	6–6.5
Carnation	Haydite, cinders, gravel	2 WP	6–7.5
Chrysanthemum	Haydite, silica gravel, cinders	WP first, later 2 WP	6–7
Sweet pea	Limestone, Haydite, gravel (calcareous)	2 WP, 3 WP to reduce bud drop	6.5–7.5
Snapdragon	Gravel (calcareous), Haydite, cinders	WP to start, 2 WP later	6.5–7.5
Stocks	Gravel (calcareous), limestone, Haydite	WP to start, 2 WP later	6.5–7.5
Gardenia	Haydite or silica gravel	WP	6–6.5
Calendula	Any medium	2 WP	6–7.5
Annuals	Any medium	2 WP	6–7.5
Annual chrysanthemum, Arctotis, Boston yellow daisy, Centaurea, Dahlia, Feverfew, Larkspur, Leptosyne, Marigold, Pansy, Salpiglossis, Venidium			
Bulbs and corms	Any medium	WP	6–7.5
Calla, Daffodil, Gladiolus, Iris, Lily			

not interfere with the solutions and yet makes starting of new roots much quicker. In washing the soil from the roots, some damage is done to the root hairs, so that their redevelopment is necessary before growth of the top can start. Once benched, the plants should receive the same cultural care as those grown in soil, *viz.*, proper maintenance of humidity, temperature, and ventilation.

Additions of ammonium sulphate should not be made during the heat of the summer. "Sticking" of buds will result. In the spring and fall, such additions are desirable if longer stems are wanted. In the summer, higher levels of phosphorus are helpful in maintaining good root action.

At the end of a year's growth, the method used in resting roses for the next season's development should be one of two. By the first method, in May or June, pumpings are gradually reduced so that the medium becomes dry enough to cause wilting. This may be repeated by first pumping tap water into the benches and allowing them to dry again. As soon as ready to be started back in growth, the stems should be cut back, kept syringed over the top, and the solution pumped once, at 2-day intervals, until new roots begin to develop.

The second method consists of cutting the plants down gradually and keeping the pumpings to the minimum while so doing. This method takes about 8 weeks.

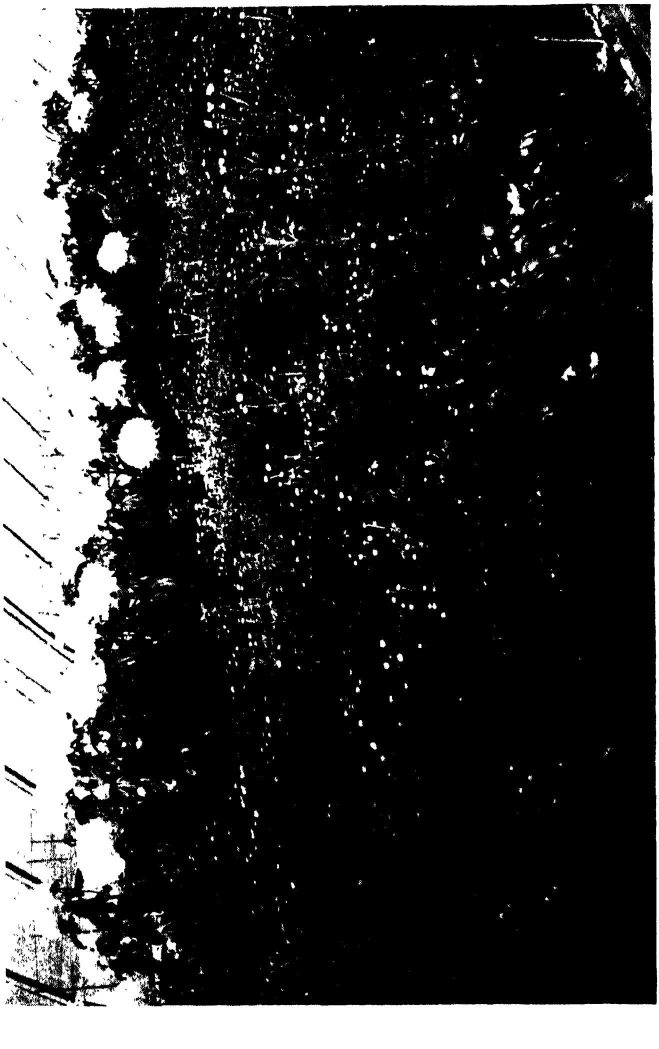

FIG. 13.—Gardenia growing in "gravel." Benched as cutting in May—photographed in July. Ohio State University greenhouses.

Fig. 14.—Bulbous iris in "gravel." Ohio State University greenhouses, 1938.

Fig. 15.—Lilies grown in "gravel." Ohio State University greenhouses, 1939.

High production has been secured with roses experimentally. The quality secured was exceptionally good.

Carnations. In localities where the summers are reasonably cool, carnations may be started as cuttings, planted directly into the gravel medium about 3 inches apart and then spaced 7 by 7 inches in May or June. However, where extreme heat obtains, field-grown plants should be used, but the soil should be removed before planting. The subsequent care is the same as when they are grown in soil. A somewhat higher production and excellent quality of stems and flowers may be expected. Carnations have done exceptionally well in commercial trials of gravel culture.

Chrysanthemums (Fig. 12). Chrysanthemums should be planted as cuttings, provided that the root systems are well developed. Deep planting is objectionable because stem rot is apt to develop. Good quality of crops may be expected. Either Haydite or silica gravel is better than cinders or alkaline gravels.

Gardenias (Fig. 13). Gardenias should be benched in May from cuttings made in March. WP solution should be used throughout their life. To secure a crop for Christmas, the pumpings should be reduced late in August until buds set. At the same time the night temperature should be held down as much as possible.

Sweet Peas. Sweet peas are started directly from seed, covered about 1 inch deep, sown where the crop is to grow. The general care afterward does not differ from that given a soil-grown crop. To reduce bud drop in the winter the concentration of the solution should be doubled. By increasing the concentration of the solution, nitrogen tends to be assimilated less rapidly, and harder growth develops. This is necessary if sweet peas in the winter are to retain the buds that have developed. Soft, succulent growth is conducive to bud drop, when light is the limiting factor. High production may be expected, with good quality.

Costs of Materials

Haydite	$4.50 per cubic yard
Cinders (properly screened)	$4–$5 per cubic yard
Gravel, local	$1–$2 per cubic yard
Gravel, silica	$5 per cubic yard
Asphalt emulsion	15 to 50¢ per gallon
Half tile	3¢ per foot
Concrete benches:	
Flat bottom	70–75¢ per running foot
V bottom raised	$1 per running foot
Tanks, concrete	90¢ per cubic foot

Snapdragons. The one precaution necessary is to be sure that low ammonium concentration is used in the solution. Practically, this means the use of WP solution to start with and no further additions of ammonium later on. Some form of nitrate should be used instead. Good quality has been produced.

Stocks, *calendulas*, and other miscellaneous annuals require no special treatments. Very satisfactory results have been secured with these crops.

Bulbs (Figs. 14 and 15). Lilies, bulbous iris, narcissi, gladioli, tuberous begonias, and others may be grown very successfully. The WP solution should be used, and the bulbs or corms should be planted as shallow as practical. Exceptional quality has been secured.

	Total cost	Depre-ciation period, years	Annual cost
Waterproofing present wood benches at 10¢ per lin. ft., 4 ft. wide	$120	8	$ 15.00
Motor and pump unit, 1 hp	100	10	10.00
Tank, installation and material, 8,000 gal	200	20	10.00
V troughs, wood for conducting solution	50	10	5.00
Pipe fittings, valves, hardware	100	20	5.00
Gravel	50	20	2.50
Time-clock installation	15	10	1.50
Operation costs:			
Electricity for pumps	....	..	10.00
Testing, weighing solutions, adding water, labor	....	..	75.00
Cost of fertilizer salts	....	..	48.00
			$182.00
Cost of comparable operations carried on in soil:			
Watering, labor	....	..	100.00
Cultivating, weeding, etc	....	..	85.00
Fertilizer, plus labor of applying inorganic materials	....	..	40.00
Fertilizer, of two manure applications per year	....	..	20.00
Spading, raking bench twice during year	....	..	40.00
Water pipe, hose, and installation not needed for gravel, depreciated over 10 years	....	..	9.00
Possibility of extensive sterilizing or changing soil—perhaps not necessary in gravel culture	....	..	?????
			$294.00

Seedlings (Fig. 16). Seedlings of many annuals when transplanted from sand to gravel (especially fine-grade Haydite) do exceptionally well in WP solution.

To give some idea of the costs involved in operating gravel-grown systems versus soil, we present the figures of George J. Ball of West Chicago, Ill., based on eight beds, each 4 by 150 feet. These figures represent one year's operation (see table on page 165).

Precautions

Water Loss. A certain amount of solution will be lost by both evaporation from the medium and intake by the plant. Tanks should be kept at proper levels by regular additions of water, which will reduce the concentration of nutrient solution, and this in turn should be maintained at the levels suggested.

Nitrites. If present in quantities above 2 p.p.m., these may prove dangerous. Their presence may be due to waterlogging, poor drainage, insufficient aeration. Flushing of the media with water will avoid this trouble.

Tanks. If miscellaneous crops are to be grown in one house, it is safer to have a separate tank for each bench. Likewise, if roses are to be dried off or carried over at different intervals, separate tanks are advisable.

Media. Do not use different media in the same bench. Trouble may occur from residual effect from cinders.

Algae. To reduce algae growth, pump to within 1 inch of the top of the medium.

sisting of a 2-quart glass fruit jar, a 1-gallon glass candy jar, a 2-gallon glazed crock (or any other suitable watertight vessel that does not react to the chemicals used or impart to the solution substances that would in any way affect the growth and development of the plant).

2. The constant-level reservoir *B* consisting of an ordinary 1- or 2-quart fruit jar (or any other suitable glass vessel), which in operation is inverted in a low flat dish *C* of appropriate size. The reservoir is filled with the culture solution, and the dish is inverted over the mouth of the upright reservoir and firmly held in position while the reservoir is being inverted.

3. The siphon tube *D*, consisting of a capillary glass tube of appropriate length and of 0.5-millimeter bore. The capillary glass tubing from which the tube is made can be obtained from any laboratory supply house handling scientific apparatus. This material can be cut into suitable lengths and readily bent over a gas flame.

"The siphon tube *D* is bent to fit over the edge of the glass dish *C*, as indicated in Fig. 17, with the short arm of the tube long enough to extend 1 or 2 centimeters under the opening of the reservoir jar *B* when in position. To place the siphon in position, the reservoir jar is tilted to one side until the edge of the jar is raised just enough to admit the end of the tube, the rim of the jar then resting on the edge of the tube. If desired, a notch may be cut or ground into the rim of the jar just to fit over the siphon tube when in position. This notching will allow the inverted reservoir jar to rest on virtually the entire surface of the rim, and its position will be stable. As the jar is tilted, air is admitted, and the solution will flow into the dish until the opening into the jar is sealed.

"When the siphon is in operation, the solution level in the dish gradually falls slightly until the seal is broken and air again enters the reservoir jar, whereupon the solution will flow into the dish and again seal the opening. The fluctuation of the solution level in the dish is not sufficient, however, to cause any appreciable change in the rate of flow through the siphon; therefore the solution may be regarded as draining from an approximately constant level. The rate of flow through the siphon is determined in part by the bore and the length of the tube, but the flow may be regulated to any desired rate within a given range by adjusting the outlet of the tube to the proper distance below the solution level in the dish. When a more rapid rate of flow is desired than can be obtained with a tube having a 0.5-millimeter bore, a capillary tube with larger bore must be employed. These capillary tubes do not clog easily, but an occasional cleaning is necessary to prevent the growth of algae or the accumulation of sediment which, of course, would decrease the flow and might ultimately stop it. The tubes can be cleaned easily by rinsing with potassium dichromate-sulphuric acid cleaning solution, followed by a thorough washing with water.

"The inlet tube *E*, with a small funnel at the top, is long enough to extend below the surface of the solution in the culture vessel. The outlet tube *F* is bent in the form of a siphon as indicated in Fig. 17. This tube is so supported that the long arm of the siphon extends nearly to the bottom of the culture vessel, or at least considerably beneath the surface of the culture solution. The level of the solution in the culture vessel is determined by the position of the outlet end of the siphon. When the system is in operation, the solution surface in the culture vessel can be maintained automatically at any level desired by raising or lowering this outlet siphon *F*.

"Aeration of the culture solution may be provided by forcing a stream of air at the rate of several bubbles a second through a glass tube *G* extending to the bottom of the culture *A*. This method has given satisfactory results. A very efficient aerating system may be set up by using a fine capillary tube having a bore of 0.5 millimeter or less instead of an ordinary glass tube with a relatively large bore. If the lower end of the capillary tube is ground to make a sharp angle with the direction of the bore, the stream of air forced through the tube will be broken into many very small bubbles as the air escapes into the liquid. This greatly increases the liquid surface exposed to a given quantity of air over that exposed when the bubbles are relatively large, thus facilitating the absorption of oxygen by the solution.

"For the growth of experimental plants in culture solutions of limited volume, some effective means of aeration is deemed essential if the indicator plants are to be considered of value as standards of comparison. Although it is well known that plants of different species vary greatly in their oxygen requirements, not a single species thus far tested by the methods here considered failed to respond most favorably to artificial aeration in culture solutions.

"To install the apparatus a suitable support must be provided to hold the solution reservoir *B* and the glass dish *C* at a height of from 5 to 10 centimeters (2 to 4 inches) above the culture vessel *A*. After the culture vessel, filled with the proper solution and with the plants and tubes supported in the manner suggested in Fig. 17, is placed in position, the reservoir *B* and the siphon *D* are so arranged that the outlet end of this siphon is just above or rests on the edge of the funnel on tube *E*. The siphons *D* and *F* are now started by applying suction, after which they will automatically take care of themselves as long as the solution reservoir *B* is not completely drained. To supply essential nutrients in solution would then appear simple. But there are many factors that must be controlled for good growth, and these will be considered in the section dealing with the culture solutions.

"The apparatus is simple in construction, compact, and very inexpensive. After being installed, the system is self-operating. It requires only that the reservoir jar be filled at the proper intervals and that the siphons be started after each refilling."

The Tank Method of Water Culture (Fig. 18)

A waterproofed tank of any material may be used. Metal, wood, and concrete are all satisfactory provided they are thoroughly coated with asphalt to prevent any damage from toxic substances (see Chap. VIII) and are absolutely waterproofed. A satisfactory size

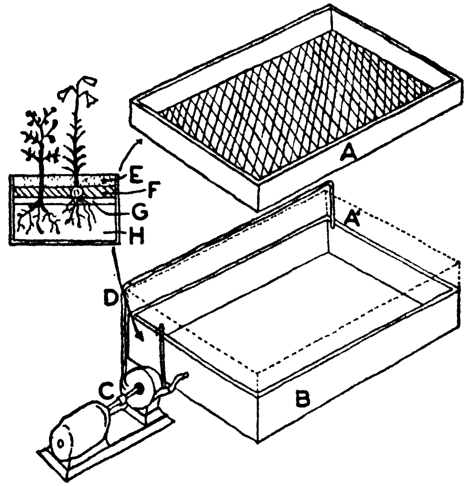

Fig. 18.—Water culture. *A*, wire-mesh tray; *A'*, tray in position; *B*, solution tank, *C*, centrifugal pump for aeration; *D*, air line; *E*, peat; *F*, excelsior over wire mesh; *G*, air space above solution; *H*, solution.

for home use is 2 feet long, 2 feet wide, and 6 inches deep. A drain should be inserted in the end as close to the bottom as possible.

Since some support is needed for the plants over the solution, the tank should be covered with a woven wire, 1-inch mesh, galvanized and painted with asphalt to prevent toxicity from zinc. The wire mesh may be either stretched tightly over the top of the tank or else made on a frame to be set over the tank or fitted tightly inside. Excelsior, sphagnum moss, or a mixture of peat moss and excelsior should then be placed over the mesh to a depth of ½ to 1 inch.

The tank may then be filled with water containing the necessary chemical elements. The formula suggested for use is the same as that indicated in Chap. VII. The young plants, previously grown in sand, as suggested in Chap. VI,[1] may then be inserted into the excelsior so that the roots are in contact with the solution. Aeration is absolutely necessary in water culture, and it could be provided once a day for about 5 minutes. The solutions should be treated as indicated in Chap. VII, from the standpoint both of additions of elements and of complete changes. The original volume of water should be restored by daily additions. This, in turn, will necessitate regular changes of the nutrient solutions, as the elements will become gradually depleted.

Outdoor tanks may be made any size by building wooden sides and lining these and the bottom, which

[1] A modification of the sand-culture method is the use of finely chopped sphagnum moss placed in a pot and watered. Small seeds may be sown on the surface, whereas larger seeds should be covered with another thin layer of chopped moss. From this medium the seedlings, with fine white roots, are easily lifted. If left for any length of time, the moss should be watered with the same nutrient solution as suggested for sand.

must be absolutely smooth, with asphalt roofing paper and coating all joints with hot asphalt. Such tanks are cheaply and quickly made. Suitable drainage should be provided for the removal of solutions whenever necessary.

The Drip Method

When tanks are used, the drip method, as described by Alexander, Morris, and Young, is very satisfactory.

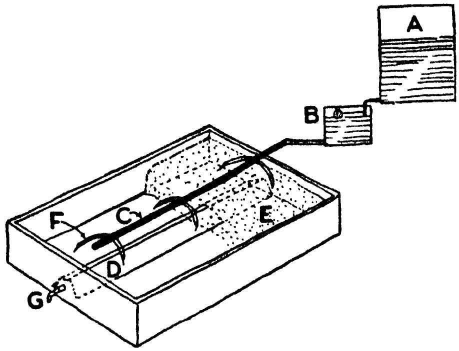

FIG. 19.—Drip method. *A*, main reservoir; *B*, secondary reservoir with float valve; *C*, header; *D*, inverted V-trough; *E*, "gravel"; *F*, dripper; *G*, drain valve.

"The drip method is the simplest and probably the most likely to be successful for amateur growers (see Fig. 19). The type of tank described is used. It is well to raise it 8 to 10 inches off the floor of the greenhouse, as the solution will be warmer there than if the tank is placed on the ground. The tank should be mounted slightly sloping, so that water will drain to the end with the outlet. Drainage is also facilitated by placing an inverted asphalt-coated 3-inch gutter pipe the length of the tank with one end extending over the drain.

"After mounting, the tank may be filled with an inert medium, such as silica sand. Screened and washed cinders also have been used successfully. More recently calcareous gravels and shale have been found satisfactory. Best results may be secured by using about a ¼-inch mesh material. If cinders are used, the fine dust and coarse material should be screened out. The remainder should be washed and leached with a weak acid solution containing about 5 per cent sulphuric acid and 95 per cent water. The leaching can best be done by closing the outlet in the tank and allowing the acid solution to remain in contact with the cinders for about 24 hours and then flushing several times with water. A second leaching and flushing are advisable. After this the medium is ready for use.

"The nutrient solution is supplied separately to each plant, a drop at a time. Small plants should receive from 1 to 2 pints per day, and large plants 3 to 4 pints per day. To avoid accumulation of salts on the surface, the medium should be flushed thoroughly with water about every 2 or 3 days, more frequently in bright or hot weather, less often in dark, cool weather.

"A steel drum from which the head has been removed and which has been lined with asphalt serves excellently as a reservoir for supplying the drip. A secondary reservoir of about 3 gallons connected to the primary reservoir and arranged with a float valve (a bathroom toilet float and valve are very satisfactory) is very helpful in keeping the drip at a uniform rate. The float valve maintains a constant level in the secondary reservoir, and consequently the rate of dripping will be the same regardless of whether the

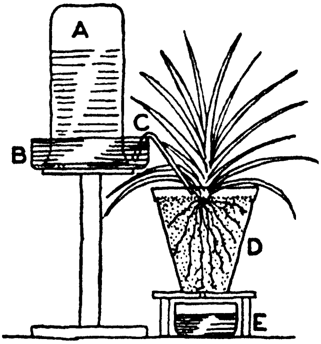

Fig. 20.—Continuous-flow method in "gravel." *A*, reservoir with solution; *B*, saucer; *C*, siphon tube; *D*, pot with "gravel"; *E*, drain dish.

main reservoir is full or nearly empty. The rate of drip may be regulated by raising or lowering the level of the solution in the secondary reservoir.

"An excellent header for conducting the solution from the reservoir to the plants may be made of black iron pipe fitted with ⅛-inch nipples. The size of the header should vary with the length of the culture tank, but a ¾-inch pipe will supply a 50-foot double row of drippers. The drippers are 1-millimeter bore capillary tubing and are attached to the nipples in the header by 3⁄10-inch rubber tubing. The nipples in the header should be spaced so that there is one dripper for each plant."

For individual pot plants a 6-inch glazed pot with a drain hole in the bottom, filled with sand or "gravel"

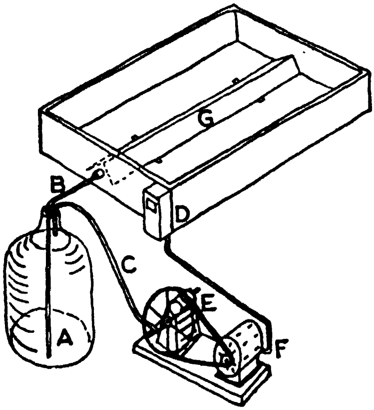

Fig. 21.—Automatically operated subirrigation box. *A*, 5-gallon carboy; *B*, hose connection for solution; *C*, air line; *D*, time switch; *E*, air compressor; *F*, motor; *G*, V-trough.

is used for the plant, with an inverted mason jar filled with solution set on a stand above the pot. To this is attached a glass tube (see Fig. 20) which will drip the solution constantly into the pot. Below the pot a glass container may be placed to catch the drip. If desired, this may be used over again in the jar, although it is best to renew the solution when the jar is emptied.

The Subirrigation Method

The subirrigation method has already been described in Chap. VIII. For this purpose "gravel" should be used instead of sand. If a small tank is employed, no mechanical devices are necessary. A tank measuring 3 feet long, 2 feet wide, and 6 inches deep will contain about 5 gallons of solution, which may be held in a glass carboy of that size. This carboy should be attached by means of rubber tubing to a ½-inch pipe inserted at the end of the tank, as close to the bottom as possible. This pipe leads into an inverted trough

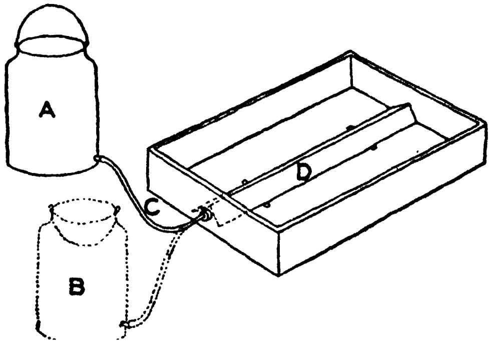

Fig. 22.—Hand-operated subirrigation box. *A*, jug in position for flooding; *B*, jug in position for draining; *C*, hose connection; *D*, inverted V-trough.

placed in the center of the bottom of the tank or box. To fill the tank, lift the carboy until it is empty, and then lower it again to the floor to drain the tank. Such carboys are heavy to handle and would have to be placed on a support above the tank while filling it, or an automatic device may be substituted (Fig. 21). The tanks or boxes should be filled with the same kind of media as recommended in Chap. VIII.

Smaller tanks (Fig. 22) or individual pots are much more easily handled in this manner and really present the most satisfactory method of growing plants on a small scale in the home. Pails or buckets may be substituted for the glass bottles as nutrient solution containers. The number of fillings will correspond closely to the recommendations made in Chap. VIII.

Since the various solutions recommended in previous chapters are easily made, they would be safer to use than the many advertised in various publications. In the majority of instances, these concoctions are not adequately prepared, and failures often result. There are some, however, that may be found satisfactory. If after using these you find that the results secured are poor, before giving up soilless plant culture entirely it would be worth while to use the suggested formulae, particularly the following simplified one:

SIMPLIFIED FORMULA

Potassium nitrate	1 oz.
Monocalcium phosphate	½ oz.
Magnesium sulphate	¾ oz.
Iron sulphate	1 teaspoonful
Water	5 gal.

The necessary chemicals may be purchased from local drug stores.

LIST OF HOUSE PLANTS THAT MAY BE GROWN WITHOUT SOIL

House plants are of two types, foliage and flowering. Although foliage plants are grown primarily for their leaves, many of them will develop flowers and seed under proper conditions. The following list is a fairly complete collection of desirable house plants which are discussed in order of their comparative desirability and tolerance to fluctuations of temperature, humidity, aeration, and general care.

Foliage Plants

Cast-iron Plant (*Aspidistra lurida*). This plant easily rates as the most tolerant house plant. It will live for months without direct sunlight, and it can withstand wide fluctuations of temperature. Because of its extreme tolerance the plant is put to many uses. The leaves are large, with long petioles arising from the rhizome. The drooping leaves give the plant a somewhat graceful appearance. Insects seldom attack it. An occasional bath will brighten it and add to its attractiveness.

Wandering Jew (*Tradescantia fluminensis*). This is a trailing vine of succulent growth with green leaves, often purplish beneath. Its requirements are few—a fair amount of sunlight and approximately 60°F. temperature. It is easily propagated by cuttings placed in water or sand.

English Ivy (*Hedera helix*). This is another popular plant, perhaps because it does well in places receiving little sunlight and heat. It makes rapid growth under normal conditions and can be trained to supports for unusual effectiveness. If a bushy plant is desired, the ends of the branches should be pinched off. These removed branches may be used as cuttings to propagate new plants. Occasionally, aphids attack the young foliage. A spray of nicotine sulphate will hold the insects in check. The variegated form, Mexican and California ivy, is attractive but not so vigorous as the ordinary kind.

Bowstring Hemp (*Sansevieria*). There are two species of this plant: *Sansevieria zeylanica*, mottled with a light color; and *Sansevieria laurenti*, which has leaves with a definite white margin. Either will exist under trying conditions. The leaves, which arise from the base, are of a fleshy, tough texture. They are propagated by division or leaf cuttings; *Sansevieria laurenti*, however, will not come true to color from cuttings.

East Indian Hollyfern (*Polystichum aristatum*). This is one of the most tolerant of all ferns for the house. It is very easily grown and prefers shade. The plant grows 12 to 18 inches tall, and each leaf is 12 to 24 inches long and 10 inches wide. Although coarser in appearance than the Boston fern, it is very vigorous in habit and stands rough treatment.

Rubber Plants (*Ficus*). This is popular with most people. It prefers partial shade. A temperature of 60 to 65°F. is best. All rubber plants do best outdoors during the summer. Frequent sponging will remove dust and eliminate clogging of the breathing pores. *Ficus pandurata* (fiddleleaf), with its large, fiddle-shaped and deeply veined leaves, is somewhat more attractive than the common *Ficus elastica*.

Creeping Fig (*Ficus repens*). This is a dainty trailing plant with small leaves close to the stem. The dense growth and rich green color make it desirable. It is native to Japan and China.

Palms. Many of these decorative evergreens are frequently used as house plants. All require a temperature of about 60 to 65°F. *Kentia belmoreana* is a graceful plant with rather broad fan-shaped leaves. The leaves of the Phoenix are finer and more graceful. In its native habitat this species produces dates. *Areca lutescens* is a rapid grower with feathery foliage on long yellow stems.

Norfolk Island pine (*Araucaria excelsa*). This plant is a beautiful evergreen, a fairly rapid grower, and quite tolerant. As a small plant it makes an excellent table centerpiece.

Japanese Grape (*Cissus rhombifolia*). This is an excellent trailing evergreen plant with three parted leaflets. Each leaf is about 4 inches long. New plants are grown from cuttings.

St.-Bernard lily (*Anthericum liliago*). This herb grows rapidly from stolons like the strawberry plant. Because of its rapid growth and trailing habit, it is useful for hanging baskets. Propagation is most easily affected by stolons, although it is sometimes perpetuated by division or seeds.

Coleus. Among these plants, *Coleus blumei* is the most common cultivated species. To produce a bushy, well-balanced plant the stems require frequent pinching to encourage branching. Full sunlight, high humidity, and a temperature of 60°F. are the cultural requirements. The easiest method of propagation is by cuttings, although seeds germinate readily and provide many interesting variations in pattern. Mealy bugs are the worst enemies of this plant. Frequent washing and syringing will help to keep the insects in check. Painting the insects with alcohol insures instant death.

Umbrella Plant (*Cyperus alternifolius*). This is a peculiar-looking plant which derives its common name from the appearance of the foliage, a long petiole with leaves (blade) arranged similarly to the ribs of an umbrella. It is native to Africa and therefore needs a warm temperature (65°F.). Sometimes mealy bugs are a serious pest.

Philodendron. This is a very interesting and rapid-growing vine although not quite so tolerant as the English Ivy. The leaves are large, bright green, and somewhat heart-shaped. The vine requires a fair amount of sunlight.

Baby's Tears (*Helxine soleiroli*). This is a dainty creeping plant with very small leaves, forming a dense mat. In homes it is found frequently on kitchen window sills where the high temperature and the abundance of moisture are particularly favorable for its development. It thrives in partial shade.

Silk-oak (*Grevillea robusta*). This plant is not particularly showy but a very rapid, vigorous grower. In its native land of Australia it becomes a tree 150 feet tall.

As a pot plant it produces a slender stem with long horizontal branches with feathery, fernlike leaves. The usual method of propagation is by seed.

Periwinkle (*Vinca minor*). This is an excellent vine for window boxes and wall vases. The variety with variegated foliage is most attractive.

Leopardplant (*Ligularia kaempferi*). This plant is used chiefly for its spotted foliage of white, yellow, or pink. New plants are started by cuttings or division.

Boston Fern (*Nephrolepis exaltata bostoniensis*). Although many people find it difficult to grow properly this is one of the most popular house plants. Ferns are sensitive and require a temperature between 65 and 70°F.; lower or higher temperatures may cause poor growth. High humidity (air moisture) is essential, and it may be provided by frequent washing of the leaves. A partial shade is preferred to direct sunlight. All ferns are propagated by runners or division. Be on the lookout for white flies, aphids, and scales.

Asparagus Fern. This plant is a native of South Africa. The species *Asparagus sprengeri* and *Asparagus plumosus* are the two most commonly used as house plants. Both produce long fronds which occasionally bear red to black berries. A hot, dry atmosphere will cause the leaves to drop.

House Hollyfern (*Cyrtomium falcatum*). This interesting plant has dark green, glossy, pinnate leaves. The fronds are long and graceful.

Dumb Cane (*Dieffenbachia brasiliensis*). This is grown as a potted plant because of its broad, 5- to

7-inch variegated leaves. It is propagated from short stem cuttings, planted horizontally in sand. The natives of Central and South America become temporarily paralyzed from chewing the canes, the juice of which has a spicy taste.

Chinese Rubber Plant (*Crassula arborescens*). This is a slow growing plant with very fleshy, oval leaves and a thick stem, growing well in partial shade with moderate amounts of water. Most Japanese gardens contain at least one of these plants which are propagated from tip cuttings or the fleshy leaves. A warm temperature with moderate humidity is necessary.

Nandina (*Nandina domestica*). This evergreen shrub is native to China and Japan. As a house plant it makes an excellent specimen with its thin branches, bright red berries, and delicately colored leaves. It thrives in shady or sunny positions. Seed is the usual method of propagation.

Copperleaf (*Acalypha macafeana*). This is a colorful plant, with copper-colored leaves. It is propagated by heel cuttings. A temperature of 65°F. is best.

Screwpine (*Pandanus*). The most common species of the screwpines is *Pandanus veitchi*. The leaves are long, variegated, swordlike, with sharp teeth on the margins. New plants are produced by offsets.

Dracenas (*Dracaena*). These are beautiful plants, grown for their variegated foliage. The genus Cordyline is similar to Dracaena, differing only in the flower parts. *Dracaena fragrans* (corn-plant) is most common, with its large cornlike leaves. *Cordyline australis* (*indivisa*) has long, dropping, narrow leaves. The leaves of *Dracaena godseffiana* appear in whorls or opposite on the stem, 3 to 4 inches long, with numerous white spots; flowers are greenish yellow. *Cordyline terminalis* has large leaves (12 to 30 inches long by 3 to 4 inches wide) in many colors. *Dracaena goldieana* is a fine foliage plant with its broad rounded leaves (7 to 8 inches long and 4 to 5 inches wide) of white and green bands. Sponging the leaves with water at frequent intervals improves their growth. Moderately warm temperature is necessary.

Birdsnest Fern (*Asplenium nidus-avis*). This interesting subject is sometimes grown as a house plant. The leaves are broad and of a delicate green color. Their arrangement suggests a nest for birds. Strong sunlight spots them.

Small plants such as Pteris fern, *Peperomia maculosa*, Mesembryanthemum, *Pilea microphylla* (artillery plant) find use as potted plants. Full sunlight is required.

Flowering Plants

Lemon, Orange, and Grapefruit. These are the most common citrus plants used as house plants. Of all flowering plants they are the most tolerant. They thrive in the high temperature of the average home. Although tolerant to partial shade, they grow better in full sunlight. On mature plants, scales are troublesome occasionally.

Garden Balsam (*Impatiens balsamina*). This old-fashioned plant is popular with most people. The stems and leaves are quite succulent, and the flowers are of various colors borne close to the stems. Pinching the terminal growths keeps the plant bushy and shapely. It can be perpetuated by seeds or cuttings.

Calla Lily (*Zantedeschia aethiopica*). This species of calla lily is well known to most people. After flowering in June the roots are dried off completely until September and then started into growth.

Amaryllis (*Amaryllis hybrida*). This South African bulbous plant has large lily-like flowers. It is a vigorous grower and indifferent to adverse house conditions. After flowering, allow the plants to die down naturally, and gradually withhold the water. Place the pots of dried bulbs outdoors until frost; then bring them into the house, and keep them dry until the middle of December. Never force the bulb into growth before it has had the necessary rest.

Cigar-flower (*Cuphea platycentra*). This is a native of Mexico. The flowers resemble a cigar, with their bright red calyx and white mouth with a dark ring at the end. Cigar-flower is easily grown in the house and is propagated by seeds or cuttingss.

Geranium (*Pelargonium*). This includes many species, such as the Fish Geranium, one of the most common house plants. The Lady Washington Pelargoniums are smaller leafed, many flowered, white to red with black blotches on the two upper petals. Madame Sellori, a variety of the fish geranium, is characterized by its variegated leaves. All species prefer plenty of sunlight. A temperature between 65 and 70°F. increases flower production.

Begonia is another old favorite. Many species are grown, but not all give satisfactory results. *Begonia semperflorens* is the most tolerant. The leaves are glabrous and somewhat succulent, and the white, pink, and red flowers are numerous. Some begonias require protection from direct sun, especially in the spring. They are easily increased by cuttings.

Fuchsia (*Fuchsia hybrida*). This house plant has been in use for many years. When allowed to grow spindly, it becomes unsightly; but when kept pruned back, it makes a fine, bushy plant.

Primrose (*Primula*). There are many species, but only three are widely grown, *viz.*, *Primula obconica*, *Primula malacoides*, and *Primula chinensis*. The *Primula obconica* is the large flowered type but is objectionable to some people, as it sometimes causes a skin rash. *Primula malacoides* has small flowers well above the foliage, whereas the *Primula chinensis* produces its flowers among the foliage. Primroses thrive at a temperature of 55 to 60°F. in moderate or full sunlight.

Cineraria. This is another easy plant to grow. The cultural requirements are the same as for the primrose except that it requires an abundance of sunlight. Aphids, red spider, and white fly have a strong affinity for this plant.

Cyclamen (*Cyclamen persicum*). This requires a cool temperature and much sunshine.

Rose (*Rosa*). Many species make good house plants if given proper attention. A temperature of 60°F. is most desirable. When the plants are in flower, a lower temperature is essential. Red spider is its most serious insect pest. Frequent washing and syringing with water will give satisfactory control when applied during bright, sunny days. Dust with sulphur to prevent the spread of mildew, a white powdery growth which appears on the leaves.

Pocketbook Plant (*Calceolaria hybrida*). This is a very attractive plant. The flowers are shaped like an open purse and are of many brilliant colors.

Poinsettia (*Euphorbia pulcherrima*). This is the favorite Christmas flower. During its growing season it requires a temperature of 65°F. and plenty of sunlight. Avoid sudden chills. The plant is propagated by cuttings taken in early summer from plants carried from the previous winter. If the flower is cut from the plant, dip the end of the stem into boiling water, or sear with a flame to prevent bleeding. The true parts of the flower are not the large red, modified leaves but the small appendages in the center.

Hydrangea. This beautiful plant seldom makes a good house plant, because it is impossible to satisfy its needs in the ordinary home.

Gloxinia (*Sinningea speciosa*). This is an interesting plant. The flowers are large and bell shaped, in velvety colors of violet to red or even white. It requires a warm, humid atmosphere and partial shade. After blooming, the tubers should be stored in a cool place until February, when they may be started into growth. Be careful not to wet the foliage. Flowering plants can be produced from seeds or cuttings in about 12 months.

Ageratum, Heliotrope, Lantana. These are all grown occasionally as house plants. They all require full sunshine and a temperature of 60 to 65°F.

Lily-of-the-valley. This fragrant flower responds quickly to indoor forcing. The "pips," or roots, are sold by many florists. The greenhouse pips can be forced any time after September. Plant the pips in a box of sand placed near a radiator or sunny window where a temperature of 65° can be maintained. In about 3 weeks the dainty bells will begin to open.

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