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At last, the standard, authoritative book on the science of growing plants without soil has been written by the originator and inventor, Dr. W. F. Gericke. Since, in 1929, he first conceived of the possibility of growing plants economically in nutrient solutions, Dr. Gericke has applied himself to study and experimentation and this book records the result.

From the preparation of the seed-bed to the final development he explains each step in simple, easy-to-follow chapters. Beginning with an explanation of the working principles of this science, Dr. Gericke gives instructions for setting up the necessary apparatus and preparing the nutrient solutions. He then devotes separate chapters to the growth of root, leaf, and seed vegetables; perennial vegetables and berries; field crops; and all types of flowers. One significant chapter compares soilless gardening and agriculture in respect to costs and crop yield.

Whether you expect to grow plants on a small scale for your own use, or carry out your chemical farming on a large scale for commercial purposes, this book will be your standard guide—your encyclopedia of up-to-date information on the subject.

THE COMPLETE GUIDE TO SOILLESS GARDENING is fully illustrated with photographs and line drawings that make it easy for anyone to follow each step of the instruction.

The Complete Guide to

SOILLESS GARDENING

The Complete Guide to

SOILLESS GARDENING

by

W. F. GERICKE

PUTNAM · LONDON
42 Great Russell Street, W. C. 1.

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THIS BOOK IS DEDICATED TO MY WIFE WHOSE UNFALTERING FAITH IN THE ULTIMATE REALIZATION OF CROP PRODUCTION WITHOUT SOIL WAS A GREAT HELP IN ESTABLISHING HYDROPONICS.

Preface

HYDROPONICS was really the second name to be applied to the science of soilless gardening. The first was "aquiculture," chosen because of its analogy to "agriculture." Later it was found that this word had already been used in another connection and so could not be employed again. "Hydroponics" was then selected because of its parallel relationship with "geoponics," the Greek word meaning "earth working," or, literally, "agriculture."

Hydroponics can now be carried on without restriction by anyone who desires to do so. But scientific research on the subject must be safeguarded, the public must be protected from exploitation, and business interests must assume the responsibility for the development of the science. My own wishes are that research and educational institutions shall profit from the growth of hydroponics, that I shall be free to conduct research and teach the new subject, without being responsible for business development except in an advisory capacity where this is needed.

Those private individuals who gave of their private funds to test the validity of new ideas, and who provided the laboratory of practice wherein the dross of impracticability was removed from the hydroponic theory, have earned the utmost consideration. They deserve the right to be consulted before any publication is made of results obtained in their plants.

It is a pleasure to acknowledge here the coöperation and aid given the development of hydroponics by the establishment of plants by Vetterle and Reinelt, Frank L. Lyons and E. W. Brundin, the California Packing Corporation, George O. Brehm, Martha Jane Dawson, Carl Gericke, Max B. Miller, Donald French, Pan American Airways, Inc., and E. O. Freund.

I am indebted to the Paraffine Companies, Inc., for providing the asphalt-paper basins; to California Redwood Association for the wooden basins; to Pacific Portland Cement for the concrete basins. These were donated to me for experimental purposes, and each material was the first of its kind used for soilless crop production.

Nurseries provided planting stock. I am indebted to Vetterle and Reinelt, George C. Roeding, John Armstrong, and Jan de Graaf for their encouragement to hydroponics with liberal donations of materials.

The good wishes of a host of scientists who have followed the development since its first announcement in 1929 have been a great inspiration, and among these I especially wish to mention Dr. B. E. Livingston.

W. F. GERICKE.

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To the solid ground
Of nature trusts the Mind that builds for aye.

—WORDSWORTH

CHAPTER ONE

Introduction

HYDROPONICS is the art and science of growing crops without soil, and its application. The word is derived from the Greek and means literally "water working." It is thus distinguished from agriculture, "care of the field." Hydroponics is based on the theory that all the factors of plant growth naturally supplied by the soil can be coördinated artificially by the use of water and chemicals into a crop-production method capable of competing with agriculture.

With few exceptions, such as the Eskimos, man in the past has been completely dependent upon the soil for his food supply. The course of human civilization has been determined largely by this dependence. Racial migrations and the opening of new frontiers have dramatized man's historical need for fresh and fertile soil. In recent years chemists have tried to create *ersatz* food by converting indigestible plant material, such as wood cellulose, into edible products. So far they have had only slight success. Efforts have also been made to reproduce photosynthesis—the natural process by which plants use sunlight to manufacture food material out of carbon dioxide and water. But hydroponics is agriculture's first real competitor.

Soilless crop production has captured world-wide attention. Thousands of inquiries have been received concerning it. My overflowing mailbox has not, however, been filled entirely with letters lauding the discovery of the world's newest crop-production method. When I first announced that crops could be grown

commercially without soil, the idea was received with skepticism by some and with outright derision by others. The work was done largely on my own time and with little aid from any scientific organization, notwithstanding requests therefor. Not until private businessmen offered their coöperation was hydroponics given a fair trial. Today proof of its worth is being provided by growers in California, New York, Illinois, Florida, distant Wake Island—a mid-Pacific fueling station of Pan American Airways—and other places.

It seems strange that soilless crop-production was not developed long ago. The immediate scientific basis for other great technological developments has been laid by a few talented men, in some cases by only one individual, but the theoretical basis for hydroponics has been known to many. More research has been carried on in the fields of soil science and plant nutrition than in any other branch of agricultural scientific endeavor. Soon after 1868 the conditions were as auspicious for the birth of hydroponics as they were in 1929.

Scientists failed to realize the true value of a principle they themselves applied in laboratory experiments. The development of water culture as a means of studying the life processes of plants is covered briefly later in the chapter. It is enough to point out that plants have grown in nutrient solutions under experimental conditions for nearly a century. Modern scientific agriculture has been greatly aided by information obtained through these studies. By no means do I wish to disparage their value.

The fact remains, however, that laboratory water culture has been aimed at but one objective, that of making better use of the soil. Not until 1929, when the theory of hydroponics was presented, was it pointed out that crop production need no longer be chained to the soil, that some commercial crops could be grown in larger quantities without soil in basins containing solutions of plant food. Indeed, it is obvious that since hydroponics requires a larger expense per unit of area than does agriculture, either yields must be larger, or there must be other compensations, if the method is to succeed commercially. And experience has already shown that it can succeed.

Some scientists who failed to realize the import of natural and field conditions have compared yields from small hydroponic basins with those from basins of fertile soil, and also with those of sand treated with nutrient solutions, using the same number of plants each. In using the same number of plants in the hydroponic basin as in the soil, these experimenters have made the mistake of limiting the productive capacity of hydroponics to that of soil. Comparison can be only by growing as great a number of plants in each case as the fertility of the culture medium can support. A greater mistake was to consider the yield from a few square feet of soil in a basin as representative of that of an equal sector of the field. How large a hydroponic basin must be to represent the conditions which will be encountered in large-scale production is not known at present. The established yields of agriculture are known, and comparison between the two systems can be made only under conditions representative of practical production and not by small experiments in a laboratory. It was the laboratory point of view and method in studying crop production that circumscribed the potentialities of water culture in the minds of plant physiologists familiar with nutrient solutions. The basin is capable of nourishing a much larger number of plants than is an equal area of soil because it can provide more water and nutrients. To utilize these fully it is necessary to provide as many plants as light conditions will permit, regardless of species, as will be shown later on in the chapter on multiple cropping.

Hydroponics is not an exact science at present. It is still in the experimental stage. The most universal of all arts—that of growing plants—cannot be changed overnight simply by following the directions on a package of chemicals. Do not believe all the exaggerated statements you may hear. Results have been extraordinary but, unfortunately, they seem to have convinced many people that tremendous yields of vegetables and flowers can be produced with little trouble and without any real knowledge of the problems involved. The idea is widely held that the nutrient solution will take care of everything and that, like Topsy, the crops will just grow. Unthink-

ing enthusiasts by the hundreds have been misled by promoters selling tank equipment and "magical" formulas at exorbitant prices. The vendors of this equipment had no valuable information to offer, nor could their customers obtain the necessary knowledge from any publications. Because the buyers were not warned concerning the limitations of hydroponics, most of their expensive projects have failed.

The problems involved in growing plants without soil are many. Supplying the proper food elements through a well-balanced solution is only one. Once the plants have started to grow, other difficulties come up. The questions of light and heat, as well as of protecting the crop from pests and diseases, must be met and solved. For example, some plants will not grow in dimly lighted basements, nor even in well-lighted houses, though certain publications have stated that they will. You must realize that the theory from which hydroponics has grown is based more on field observations, which cannot be expressed in neat tables of figures, than on laboratory measurements, which lend themselves to such statistical treatment. The successful farmer's instinctive ability to coördinate all the growth factors of plants is indispensable. Thus, your success or failure in hydroponics will depend more upon skill in working out a proper technique indescribable in textbook language than upon possession of a simple chemical formula. You must combine to some extent the knowledge of the chemist, the botanist, and the farmer, arming yourself with an understanding of the fundamental requirements of plant life and developing through your own alertness and insight a sure sense of the technique required.

The productive powers of hydroponics dwarf those of agriculture. Yields far outstripping those obtained from some of the richest farming sections of the nation have been produced on experimental plots. Yet these yields, large as they have been, by no means exhaust the possibilities. A later chapter will show how several different crops can be grown simultaneously from the same basin, each of them providing larger harvests than can be taken from the soil. This has already been done in large-scale experiments. It promises to overcome one of the major objections to hydroponics: the high cost of equipment

for some crops. Nevertheless, caution should be employed in selecting the crops to be grown; some will always be grown more economically in soil.

Social Implications

Soilless crop production presents a challenge to the amateur. The main purpose of this book is to aid him in mastering it. As the rules of operation become standardized, the wage earner with a small plot of ground at his back door may regain a measure of economic independence. His food supply will be more under his own control so that his livelihood will no longer depend solely upon national philanthropy or the weekly pay check. As a means of providing subsistence to those thrown out of employment by recurring economic depressions, hydroponics deserves the utmost consideration from government.

In the commercial field soilless crop production is now being employed successfully. Experiments indicate that it will soon invade new regions and new fields of agricultural production. Hydroponics can be used wherever good climate prevails. Thus, states like New Mexico and Arizona, lacking in soil resources but blessed with mild temperatures and plentiful sunshine, will find it ideal.

Hydroponics offers much to those who are interested solely in growing flowers for their own enjoyment and the beautification of their homes. Daisies, snapdragons, begonias, and dahlias are but a few of the garden flowers which can be grown to their natural size and beauty in neatly concealed tanks.

Nations such as Italy and Japan, which are worried by crowded populations and inadequate agricultural land, could easily use it to multiply their production of foodstuffs manifold. Once their hunger is satisfied from within their own boundaries, the reasons for seizing the rolling wheat fields of their neighbors might be swept away.

The Cycle of Conservation

Finally, hydroponics will help us to conserve our natural fertilizers and to solve our future fuel problems. Of the fertilizers commonly applied to the soil only nitrogen can be recovered completely. But in hydroponics the plant food provided need never be wasted. The dry plants can be burned and the ashes used for nutrient solution. In this way the so-called "cycle of conservation" has been completed for the first time.

The carbohydrates produced by the plants will form a vast reservoir of cheap, available power. Chemists have shown their ability to rearrange the molecules of carbon compounds and convert them into fuel. The greatest natural production of carbohydrates now takes place in certain sections of the Hawaiian Islands. In these regions 24,000 pounds of this material in the form of cane sugar can be grown per acre. By hydroponics, however, 180,000 pounds of potatoes can be produced in many areas from an acre of tank space. They will contain about thirteen tons of natural carbohydrate in the form of starch. In some cases ten to fifteen tons of corn, corn stalks, and leaves containing additional chemical energy can be grown from the same tanks at the same time. And, while cane sugar has been produced in the quantities named only in certain parts of Hawaii, corn and potatoes can be grown by hydroponics over vast areas of the earth's surface. The fuel of the future, after our stocks of coal and oil have been expended, may well be made from carbohydrates produced by the hydroponic method.

Before soilless crop production can realize its full potentialities, however, the widest and most intelligent use must be made of it. Misconceptions must be swept from the public mind. The technique must be placed on a thoroughly scientific and practical basis. It is with this end in view that I have written this book. It would have been preferable to clarify the scientific basis of the method in another book before releasing this more popular one. However, the great demand for information prevented adoption of this procedure. Within these pages you will find the science of soilless crop production reduced to terms which I trust will be understandable to all.

Water Culture

The task of finding out how plants feed and what they use for food has occupied the attention of men for thousands of years, beginning before the days of Aristotle. But the true science of plant nutrition is of more recent vintage. It was not until the dawning of the nineteenth century that the facts obtained through years of earnest if somewhat ineffective research began to dovetail into a complete story. Once the basis had been laid, however, discoveries followed at a rapid pace.

The story of these discoveries cannot be separated from that of water culture. To arrive at the beginning of this development we must go back to the days before chemistry revolutionized scientific research. Handicapped as they were by lack of equipment, the scientists of that era had already found that certain sprigs would grow if partly immersed in water. Some produced only roots; others roots and leaves. After a short time these sprigs stopped growing and the early observers rightly inferred that this was due to lack of food. Still they had no idea that nutrients could exist in water, nor did they know in what forms this food existed.

Real water culture dates from 1860 when Knop, a German agricultural chemist, and Sachs, a botanist, first added chemicals to water and obtained nutrient solutions. Knop may rightfully be called the father of water culture. His experiments laid the groundwork for those which later led to hydroponics. He was concerned with using this method to study the basic relationship of soil to crop production. Sachs was more interested in studying plant processes and thus adding to botanic knowledge. In the end Sachs' point of view prevailed. It is for this reason that scientific literature from 1860 to 1929 is utterly devoid of any suggestion that water culture principles might be applied to crop production without soil. Nowhere in the history of technological development do we find another instance in which principles widely used in laboratory work have not provided sooner a scientific approach to the problems of practical production. The formulas for the nutrient solutions might well have been used for a venture into

the field we now call hydroponics. Instead they were diverted to a relatively lesser endeavor.

In his first experiments in 1859 Knop grew plants in natural water without mineral nutrients. Seeds were sprouted in sand or fiber netting. The seedlings were then inserted in holes made in a rigid support, usually cork stoppers, held tightly by a cotton wadding, and suspended in glass or earthenware containers filled with liquid. Thus, Knop established the technique now used universally for laboratory experiments. By this method Knop also found that a plant can make an appreciable gain in weight simply by using the food contained in its seed and that the seed provides nourishment to those parts of the plant which form first. From this Knop concluded that the growth of vegetal tissue of plants is proportional to the nutrient content of their seeds. This theory has since been accepted by plant physiologists.

By this time it had been established that, if soil nutrients were to be used by plants, they must be present in soluble form. It was also known that the amount of soluble plant food in the soil was very small compared to that which was insoluble. This information provided a scientific basis for Knop's future work. However, methods had not yet been devised for measuring such properties of the solution as osmotic pressure. Nor did scientists have any clear idea as to what these properties might be. So, while Knop knew that solutions which were too concentrated might prove harmful, he did not know how this harm was done. Nevertheless, in 1860 he succeeded in growing plants weighing many times more than their seeds and containing a much larger quantity of nutrients. In 1868 buckwheat weighing 4,786 times and oats weighing 2,359 times more than their original seeds were produced by others using Knop's method. This established beyond doubt the fact that normal plants could be grown without soil.

Knop had a fairly good idea of what elements were necessary. As early as 1842 another investigator had compiled a list of nine elements which he believed were the essential ones provided by the soil. A first concern of agricultural chemists and botanists was to determine which elements were needed and

which were not. There was no unanimous agreement on this point, nor is there today. From 1860 to about 1920 most scientists thought nitrogen, calcium, magnesium, phosphorus, potassium, sulfur, and iron were the only essential elements from soil. But during the past twenty years, as purer materials have become available for laboratory research, we have found that the "trace elements"—boron, copper, zinc, and manganese—are also required.

From a wide variety of compounds Knop finally selected calcium nitrate, mono-potassium phosphate, and magnesium sulfate as the chief ingredients of the nutrient solution. Each of these supplied two of the essential elements. Consequently, he was able to keep the concentration of the solution at a low level, at which plants grow best.

Nevertheless, Knop's choice of chemicals was not a good one. The compounds contained elements which were not used in the same quantities by the plants. As one was absorbed, an excess of the other was released and entered into another combination in the solution. In time the acid-alkaline reaction of the liquid changed. This was contrary to the pattern of nature, for the soil solution from which plants derive nourishment in agriculture changes very little if at all. Knop's nutrient solution, on the other hand, became progressively more alkaline. Knop realized this and specified that a good nutrient solution should be slightly acid.

Molecules and Ions

Knop made this recommendation before the theory of electric dissociation of molecules was even dreamed of. It was known in his time that plants exercise "selective absorption" preferring some elements to others. On this principle it might be argued with some validity that it makes no difference how, or in what quantities, the various elements are supplied in the solution. The plants simply absorb what they want and leave the rest. Knop, like the other scientists of his time, had no way of knowing what effect this residue would have on the properties of the solution and on the plants themselves. Today

the theory of electric dissociation of molecules tells us that salt molecules in a solution split up into particles, or ions, carrying positive and negative electrical charges. The positive ions cannot exist unless an equal number of negative ions is also present. As it happens, plants prefer nitrate ions (NO_3^-) above all others of negative charge. For this reason nitrogen is absorbed quickly and, unless an equal number of positive ions is also absorbed, the solution will turn alkaline. The most preferred of the positive elements is potassium. Consequently, there being no other modifying factors present, a good nutrient solution must have more nearly equal portions of available nitrogen and potassium than of any other elements. Each of the major elements in the solution must be considered in relation to another of the opposite electrical charge.

Knop's Formula

In Knop's formula of 1868 he added, to one liter of water, one gram of calcium nitrate, .25 gram of magnesium sulfate, .25 gram of mono-potassium phosphate, .12 gram of potassium chloride and a trace of iron chloride. In this mixture the ratio of positive potassium ions to negative nitrate ions is about two to eight. No wonder, then, that his solution turned alkaline shortly after plants began feeding from it.

Plant Physiology

Looking back upon Knop's experiments, we see that they threw considerable light upon the question of salt proportions in the solution. Before taking up this important point, however, let us consider the influence of modern chemical analyses upon water culture. New developments have made it possible to measure the osmotic pressure of a solution. Osmotic pressure is a highly important physical property of the liquid. It derives its name from the process called *osmosis* by which liquids pass through the permeable membranes or tissues of plants. The movement takes place from the region of high water concentration into that of the low. This is because water, like gas,

always flows from a high-pressure area into a low-pressure area. A solution high in solutes has fewer water molecules per unit volume than one low in solutes. The force of this flow acting on the dissolved substances in the solution and measured as the pressure they exert on a membrane through which they cannot pass is the osmotic pressure.

If roots are immersed in a solution which is too concentrated, this pressure may cut down their intake of water or even draw water out of them. In this way the plant's life processes are deranged. The osmotic pressure is also a measure of the number of molecules and ions in a solution. It is one of the three ways of expressing the concentration of the liquid. The other two are by parts per million, or the ratio of chemicals to water by weight, and by molecular concentration.

To return to the question of salt proportions. Many other investigators have tried various combinations of chemicals in nutrient solutions. The most extensive work in adapting some of the newer concepts of physical chemistry to the use of such solutions was done at the Laboratory of Plant Physiology, Johns Hopkins University. The pioneer work done there on salt proportions in solutions of various molecular concentrations and osmotic properties played an important part in laying the foundation for hydroponics.

Water culture supplied the answers to such important questions as what, when, how, why, and how much of certain elements are necessary for plant growth. Many scientists in all parts of the world have contributed to the knowledge now amassed on these points.

The technique used to determine what elements are essential was quite simple. A mixture was made from which one certain substance was missing, and the plant was then studied to see what effect lack of this element had upon it. The absence of those elements needed in large quantities usually had a more pronounced effect than that of those required in small amounts. This did not hold, however, for those elements which, like iron, play a specific role in plant processes. The effect of absence of these elements is treated in Chapter VII, "Symptoms."

It has long been recognized that the composition of a plant does not remain constant throughout its existence. This raises the question: Does the food requirement of plants vary according to the conditions under which they grow? To explain the variation in a plant's composition, we consider that it is composed of two parts: (1) the food which it actually needs, and (2) that which it does not need but stores up in its tissue. It is the second part, absorbed during the latter part of the plant's growth, which causes variations in composition. It has been possible, by the use of water culture, to withhold varying amounts of certain elements from plants during their latter growth stage. In this way scientists have determined how much growth a plant can make from any given quantity of nutrients absorbed during its early growth. In other words, it has been possible to find out just how much food the plant requires to grow normally at any age. From this we have learned that there is a period late in life when the plants absorb only a very small amount of nutrients.

The question of how plants absorb their food has provided the basis for a most intriguing study. We know that they have the power of selective absorption, being able to take one element from a compound and leave the other. The theory that some certain combination of chemicals would ultimately prove to be the best under all conditions had to be considered in the light of this fact. Now an element taken up separately by the plant is absorbed as an ion. Two ions of opposite charge taken in together will have the same effect on the solution as if they were united in the molecule of a chemical compound. This has a most important bearing on the composition of nutrient solutions. For the reaction of the liquid remains most constant when elements are absorbed as if they were complete molecules. Therefore, the elements should be paired in the solution. Each has an opposite which should be used at the same time, so that they will be absorbed as a unit. Water culture experiments not only opened the way to this discovery but also provided the knowledge as to which elements should be used together. From a great amount of such study a formula was finally evolved which incorporates the chief theoretical features

as well as the evidence derived from physiological studies and plant analyses. In this way the physiological basis for hydroponics was laid. The basic formula will be discussed more fully in the chapter on nutrient solutions.

How much of each element does the plant need? To answer this question we must first answer another: How much growth can a plant make from a given quantity of any one nutrient absorbed? By multiplying the weight of the plant by the percentage of each element it contains, we can determine how much of each has been absorbed. The plant may take in more of some foods than it needs, so that composition is not always an accurate answer to our query. Nevertheless, we must know its composition not only at maturity but also during any of its various growth stages. The elements within the plant stand in complementary relationship to each other. A heavy intake of one will lower the intake of others. Consequently, the amount of any certain element contained in the plant may vary over a wide range. This fundamental complementary relationship between the various food factors must be considered. If we know the range of variation in composition among the different plant parts, and the causes thereof, we can forecast how much growth a plant can obtain from a given quantity of food. It was this knowledge which made it possible to compound a chemical formula which would insure the most efficient use of all nutrients.

The question of why various elements are needed has received a vast amount of study and undoubtedly will continue to draw attention for years to come. There is still much to be learned. At present our knowledge is limited to those elements which are constituents of specific chemical compounds or perform some definite function in plant life. Nitrogen is required as a raw material for proteins manufactured by the plant. It is the only element which we find fixed in a specific chemical product in practically the same amount that is absorbed. For this reason analysis of a plant for its nitrogen content will also reveal the amount of protein it contains. Phosphorus plays a part in the formation of new cells. It is particularly abundant in the growing parts of the root tips and enlarging shoots. At

maturity large amounts of this element are stored in the seeds after having performed their specific function in the formation of new cells.

Sulfur is also a constituent of proteins. Magnesium is used in the synthesis of chlorophyll, the green coloring matter of plants. Calcium is a binding material which holds together the cells of various plant tissues. So vital is this function that the absence of calcium causes more profound disturbances in many species of plants than does lack of any other element. Potassium seems to act more or less as a helper to other elements. It does not enter into any specific chemical compounds inside the plant. The amount of nitrogen absorbed, hence the amount of protein that can be manufactured, is related to the absorption of potassium. Yet the actual synthesis of protein by the plant appears to bear a closer relationship to the amount of calcium rather than potassium which is present. Iron is needed for the manufacture of chlorophyll but is not a constituent of the pigment. The function of the trace elements—boron, manganese, zinc, and copper—has not been clearly established. It seems to vary with the amount of light provided to the plant. Still this can be said for all elements, since light affects growth and is thus reflected in the nutrition of plants.

There is no doubt that the data accumulated through water culture experimentation facilitated the birth of the soilless method of crop production in 1929. It was certain to be discovered in time. No insuperable barrier to discovery remained once the general precepts had been established and it became known that crop production required a proper coördination of all the various growth-affecting factors.

Hydroponics

For three quarters of a century before hydroponics, water culture was used solely as a laboratory method of studying plant nutrition. The scientific contributions mentioned in the preceding section had established its value as an aid to experimentation. Supposedly, this was the extent of its potentialities. The phrase "crops grown without soil" was never used to de-

scribe water culture experiments, nor were scientists interested in the possible crop yields of water culture as compared to agriculture. They were interested solely in growth processes. Tiny plants weighing only a few grams supplied all the experimental material needed. The feeling prevailed that plants could be grown in nutrient solutions only under rigidly controlled conditions, with pure water, pure chemicals, pre-sprouted seeds, glass bottles, and a meticulous technique. Had any of these pure laboratory features proved indispensable, hydroponics would never have been possible. It was necessary to prove that none of them was really needed to grow plants without soil.

The preliminary work in hydroponics was devoted to finding satisfactory substitutes for water culture methods and to answering one all-important question: Can nutrient solution compare favorably with soil in production per unit area? If not, the whole idea would be worthless. The first step in hydroponic development, then, was to determine what yields might be obtained from a given area of nutrient solution exposed to good light under the normal conditions of field or greenhouse. To do this it was necessary to grow plants on a rather large scale.

Basins had never been used before. They presented several new problems. They had to be constructed from materials such as cement, metals, and certain woods which were supposedly toxic. In practice, it was found that the effect of harmful elements in these materials had been accentuated by the unfavorable conditions of laboratory climate.

Some way must then be found to introduce plant food into the water. In laboratory tests this had always been done by making a separate stock solution of each salt and adding quantities of each solution to the water separately. The small containers were then agitated so as to obtain a thorough distribution of chemicals. This could not be done with large basins. Various methods of mixing small amounts of chemicals into the basins were tried. Ultimately, such mechanical means of obtaining a thorough distribution were found to be unnecessary. The different solutions were simply poured into the water at various points and natural diffusion did the work of distribution. It

made no difference if the chemicals were not distributed uniformly, so long as the plants all received their minimum food requirements. They were able to grow equally well under a fairly wide range of concentration in the nutrient solution. Thus, a blow was struck at one of the established concepts of water culture. Constant conditions and concentrations in the solution were shown to be unnecessary.

The corks used in water culture held the plants in their proper relation to the solution but could not perform the functions of soil. In hydroponics it was hoped to reproduce the natural conditions of growth as accurately as the use of artificial means would allow. The first support used in large basins was composed of stiff paper board with holes cut in it for the insertion of rose plants. Some of the flowers failed to grow well because of the high reflection of light and heat from the paper surface.

In another experiment a variety of different plant species were wedged between laths nailed to the top of the basin. The solution was not covered. Again some of the plants failed; this time because the air immediately above the solution was too dry.

Next, burlap was laid on a wire netting attached to the basin and sand was poured on top. Seeds were sown in the sand. This arrangement was not designed for large-scale production or for ease of handling. Today it has been replaced by the litter seedbed. But in these early experiments the plants did well. For the first time seeds were sown in the same material used to support crops in the nutrient solution. This established the fact that pre-rooted plants were not necessary.

Soon two more pillars were swept from under the old water-culture theories. It was proved that neither pure chemicals nor pure water was needed. One by one the old concepts had begun to fall and hydroponics began to develop.

Still another feature of water-culture technique found to be unnecessary was the practice of adding each chemical to the solution separately. To get away from this a mixture of dry chemicals was encased in gypsum and the resulting "plant pill" placed in the basin filled with water. The object was to insure

a slow diffusion of the elements, thus doing away with the necessity for frequent additions to the solution. After gypsum, waterproof paper and glass bottles were used to hold the chemicals. Finally, all of these were found to be superfluous. The dry mixture was simply added to the water and allowed to dissolve.

Development of Hydroponic Technique

Once the physical equipment such as basins and seedbeds had been developed, attention was turned to the cultural technique required for hydroponics.

Experiments were conducted both out of doors and in the greenhouse. Some crops were not adapted to both habitats; it was necessary to grow them under diverse climatic conditions in order to see what differences in yield and quality might result.

Consideration was also given to the nutritional and cultural requirements of the different plant species. Species are living evidence that varying requirements exist. Their growth together in the same soil and under the same natural conditions also proves that they have some characteristics in common. But hydroponics had eliminated the soil. It was necessary to find out how the various species reacted to their new environment. Observations revealed no general rule pertaining to this point. Two species which acted quite similarly in soil might differ markedly in their characteristics when grown by hydroponics. But the reverse of this proposition was also true.

By this time it was evident that, while hydroponics could be a better cropping method than agriculture, it could also be a poorer one. The margin of safety against the development of poor growing conditions was much smaller in soilless crop production. For example, it was found that the liquid solution has a much lower resistance to chemical change than does the soil. Thus, experiments were required to find out how poor growing conditions might develop and to discover methods of forestalling them.

Different varieties of roses were grown in the greenhouse and also in outdoor basins. They differed much more widely in

their adaptation to water culture than to soil. It then became clear that a number of factors which afforded little or no difficulty in agriculture would be of importance in hydroponics. The adaptability of roses to hydroponics was governed by the type of root stock to which they were grafted or budded, by the age of the stock, the state of dormancy, the season of the year in which they were planted, and the methods of root pruning used. All of these factors were apart from the general features of cultural technique.

Data were collected on the yield, composition, and general quality of a large variety of field, vegetable, and floral crops. Experiments conducted in 1929 supplied the first insight into the tremendous productive capacity of the new cropping method. They showed that multiple cropping would be practical in hydroponics and would make possible yields per unit area running from ten to fifty times as large as the average obtained by the single-crop, field system of agriculture. Such yields, it appeared, could be obtained over large areas of the earth's surface. It was simply a matter of deriving the utmost benefit from available sunlight by maintaining as much green vegetation as possible on each unit of area.

Most of the research on plant composition was done with wheat. By withholding certain nutrients, or otherwise radically changing the composition of the solution during the latter growth stage, one could alter the composition of the grain. From these experiments it was possible to determine the minimum and maximum amounts of each food element that could be absorbed. It was then an easy matter to find out generally the amount of chemicals required to produce a unit gain in weight of the plant and how much the chemicals would cost. The data showed that this cost would be too high to make wheat production feasible but that crops notably high in water, starch, or sugar (such as potatoes) could be grown at a surprisingly low cost for chemical food elements.

Another discovery, perhaps more obvious than some others, was that a cultural technique would have to be worked out for each separate plant species. Plants differ from each other in complexity of structure and life processes. The more compli-

cated the plant, the more specialized must be the technique for handling it. Annual plants propagated from seed are easiest to grow. Some bulbs are also easy; others present great difficulty. Perennials, with their complex life machinery and period of dormancy, usually require the most painstaking care.

Probably the outstanding revelation of these experiments was that study of plants, of their adaptability to varying conditions, and of individual differences is more vital to success in hydroponics than the ability to handle physical equipment and provide the proper mixture of nutrients. It is by studying plants as crops rather than as test materials for the laboratory that you will master the principles of soilless crop production.

The evolution of water culture into hydroponics has been the story of the use of ordinary materials and methods to reproduce natural growing conditions. The soil is a vast reservoir of water. Therefore, a basin is needed. Soil provides vegetation with eleven food elements in solution.* Thus, these must be added to water made available to plants grown in the basin. The soil provides support by anchoring plant roots which are then immersed in the soil solution. Hence, a seedbed must be provided to support the plants in their proper position relative to the nutrient solution. Hydroponics is an artificial but not an unnatural crop-production method, based upon those same principles which nature has set up as the pattern of plant life.

Plant physiology has provided the foundation for hydroponics. Hydroponics has outgrown the older science in that it is concerned with more than simply the study of the fundamental relationship of the various plant processes. Hydroponics coördinates the other sciences which deal with plant growth and use into a system of production that is independent of fertile soil, the very foundation of agriculture.

* They are nitrogen, potassium, phosphorus, calcium, magnesium, sulfur, iron, manganese, boron, zinc, and copper. The symbols used in chemistry for the eleven are, in corresponding order: N, K, P, Ca, Mg, S, Fe, Mn, B, Zn, and Cu. They exist in simple chemical combinations known as salts, acids, or bases which are the forms in which the elements can be purchased.

CHAPTER TWO

Apparatus

IN SETTING UP a hydroponicum, as the soilless farm or garden hereafter will be called, you must first construct basins to hold the nutrient solution. This is a simple task. First carefully determine just how large the basins should be. Lakes and rivers markedly influence climate in the surrounding country. To a smaller degree the same thing is true of hydroponic basins and the solutions they hold. The influence of surface area and depth of the liquid on plant growth depends primarily on basin size. It is not the engineer but the plant physiologist who has the final word in basin design.

HYDROPONIC BASINS

While the basins are designed to replace the field, they cannot reproduce exactly the growth-influencing conditions prevailing in soil, even when the basins are so embedded that seedbeds resting upon them are level with the surface of the earth. Plants grown in such basins are better protected from sudden changes in climate than are those grown from basins aboveground. Even so the conditions scarcely parallel those in soil. For example, roots are prevented by the basin wall from spreading out and naturally equalizing the temperature and moisture content over large areas. In soil this is a most important means of maintaining equal conditions throughout the field. Because basin materials differ greatly in their ability to transmit heat,

temperature conditions in the basin may be either better or worse than in soil. The exact bearing of these factors on hydroponics is not fully known, but they do illustrate the fact that hydroponics is an artificial production method capable of superiority over agriculture only when intelligently used.

Depth of the Basin

How deep shall the basin be? How much basin area is required to give the equivalent of a certain area of ground? Answers are provided by a comparison between the basin and its counterpart, the field. The depth to which various crops penetrate the soil, the amount of available water held in the root zone under ordinary conditions, and the amount needed to provide a given area of soil with the proper supply of moisture—these are all clues to the required depth of hydroponic basins.

The basins should be large enough to make frequent additions of water unnecessary. Thus, they should be deeper in dry climates where plants absorb water quickly. The most efficient depth under most conditions is about six inches. Basins somewhat shallower or deeper—say, five inches or seven inches—will be about as serviceable. Don't build them much deeper or shallower than that if you wish to grow annual crops.

A cubic foot of water applied to dry soil will wet about four cubic feet of average loam to its optimum field capacity; that is, it will provide this volume of earth with as much water as it can hold without becoming wet enough to harm plants. The roots of most annually seeded crops occupy only the top two feet of the soil. At its highest optimum moisture content, then, the root zone will contain about six inches of water, or the same amount as a filled basin six inches deep. Much more than this amount in the root zone at any one time will drown most plants. On the other hand, many crops grow properly with less water available to their feeding roots. It follows that the six-inch basin need not be kept full constantly.

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Provide adequate air space between the seedbed and the solution. Air is indispensable to the roots of most vegetable

and floral crops. If the air space is too large, however, the roots may dry out and lose their ability to conduct moisture. The six-inch basin is well designed to overcome this difficulty in the case of deep-rooted crops such as corn and beets. The water may be allowed to recede to a depth of three inches without injury to these plants. In this way a three-inch air space is created which will provide sufficient air without drying the roots. If the basin is shallower than six inches, the space may not be wide enough. If the basin is much deeper and the water is allowed to drop to the three-inch mark, the space may be too wide. For an illustration of this see figure 10, in the section on aeration. In general, you should adjust the air space to the needs of individual crops, but a larger space will be needed in very wet climates than in dry. Remember, the basin is not merely a solution container; it also determines by its depth the relative position of the solution to other factors affecting plant growth. Essentially any depth can be used if other factors are adjusted accordingly.

Basins much deeper than six inches are often wasteful of plant food, for, to keep the concentration in the solution at the required level, more nutrients must be added than are really necessary. If the water contains elements not absorbed by the plants, their concentration in the solution will increase as the other substances are used up. In time this concentration becomes excessive and the basin has to be drained. Where the water used has a high natural content of such non-essential elements you will be forced to drain and refill the basins quite frequently anyway. This is easier to do when shallower basins are used, and more economical.

In all but a few exceptional instances, therefore, the basin six inches deep reproduces the most natural conditions for plant growth and hits a happy medium between the faults and advantages of other basins. Under some conditions, chiefly arising in the growth of trees or deep-rooted perennials, deeper basins are advantageous. (These will be discussed further in the chapters dealing with water and aeration.) Also numerous shallow-rooted flowers, such as pansies and begonias, do well

in three-inch basins. But it is safe to say that, all factors being considered, the six-inch basin is the most practical.

Area of the Basin

The areal dimensions of hydroponic basins are determined primarily by convenience except, as already noted, when they encroach on the problem of minimum size. The minimum practical width of basins for garden use is two feet, or about as wide as easy reach of the arms will permit. This size will accommodate most annual plants and small perennials grown in the average home garden. Narrower basins can be used to produce tall crops, such as tomatoes, but cut down the number of species that can be grown. Any type of crop may be grown in a wide basin. Also, in small basins, the concentration of plant food in the solution changes more rapidly with temperature, air, and moisture changes. Small amounts of chemicals cannot be mixed accurately enough to obtain the desired properties of the solution unless very painstaking methods are used. A small seedbed is more difficult to construct properly than a large one. And, finally, the symptoms of unfavorable growing conditions are not so easily diagnosed.

Search for Suitable Materials

In water-culture experiments, small containers made of glass or glazed pottery have always been used. Because large containers were not needed, no thought was given to the suitability of crude building materials. Consequently, the search for hydroponic basin materials had to be pioneered. Laboratory studies showed quick-drying, asphalt enamels to be suitable for coating glass jars in which plants were to be grown. Asphalt roofing paper, though it is not strong or very durable in water, was used for the first experimental basins (figure 1). By bending the corners and sides upward into a continuous piece, the paper was fitted inside wooden frames. No incision was made for the corners. The paper was held in place by strips of wood which allowed for contraction and expansion as air tempera-

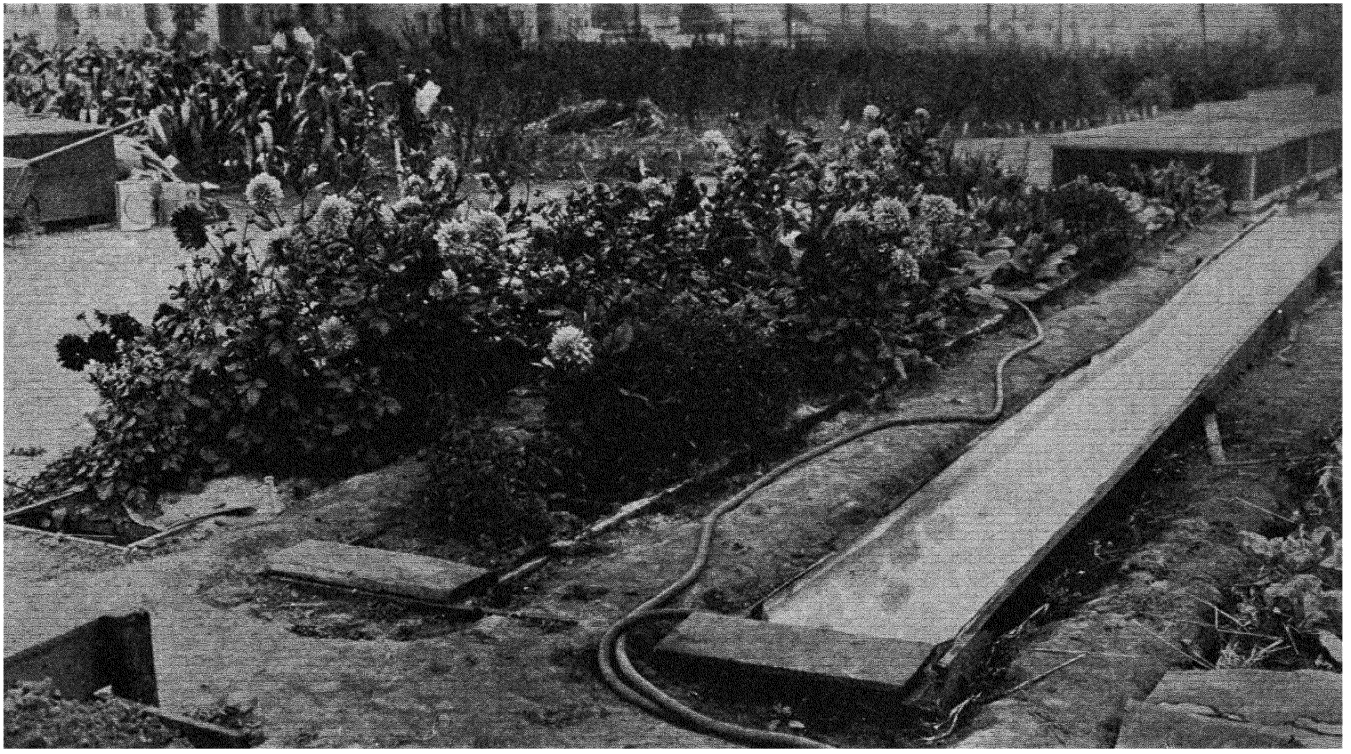

Fig. 1. The first basins were lined with tarred paper, an asphalt impregnated mat. Occasional painting with asphalt kept them serviceable until more permanent materials could be tested. Reported in "American Journal of Botany," Vol. 16, p. 682, 1929.

tures changed. Several coats of asphalt enamel were then applied. The basins proved serviceable. After these first tests had revealed the possibilities and established the basis for hydroponics, physiological studies were made of other basin materials including wood, concrete, and sheet metal.

The Use of Concrete

Mix and work the concrete that its porosity will be reduced to the minimum. Also finish the sides of the basin with neats (pure) cement to make them water tight, thus providing the best protection against the action of magnesium sulfate and other salts contained in the solution. Concrete basins, being of lighter construction than is usual with concrete, may be more vulnerable to damage by freezing unless properly reinforced.

Make your forms and pour the mixture into them. Steel forms are probably the most practical on large jobs. Any grade of Portland cement may be used, but those low in magnesium content will probably last longer. The grade of sand, rock, and gravel ordinarily used is suitable. Unless the basins are to bear an unusually heavy load, the sides need be no more than one and one-half or two inches thick.

Concrete contains alkaline substances which must be removed at least partially before the basins are used. This can be done by leaching; that is, by filling the basins with water, allowing it to stand, and then draining them. One week's leaching will reduce alkalinity to the point where the basins can be used. After this time they must be filled and drained several times. It will take much longer than this before alkalinity becomes so low that it gives no trouble at all. During the first few months of use, therefore, make adjustments in the solution to counteract the continued diffusion of alkaline substances from the concrete. You may use the nutrient solution to complete leaching by draining and refilling the basins two or three times more than is necessary. You may even tempt fate and use the basins before they are leached if you give them a coat of quick-drying asphalt enamel and use the solution for leach-

ing. The asphalt provides only temporary protection, however, and complete leaching is the recommended procedure.

Practical concrete basins may range in size from 10 feet long and 2½ feet wide to as large as 150 feet long and 50 feet wide. Concrete is a strong competitor with other materials where large construction is contemplated. It also is best for a basin that will be partly or wholly surrounded by soil. On the other hand, it cannot be manufactured in readily assembled basin sections at reduced cost by mass production of complete equipment.

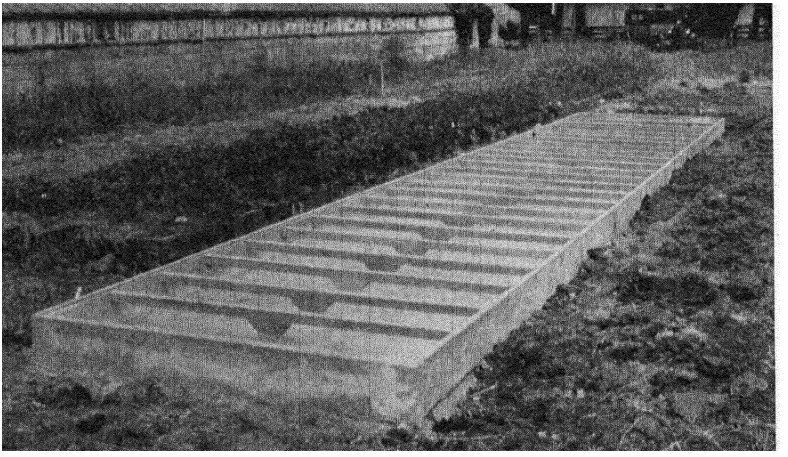

Fig. 2. First concrete basin, 6 feet wide, 36 feet long, six inches deep or 1/220 acre inside measurement. The concrete cross-bars to hold wire netting have since been discarded.

Sheet Metal

Whether sheet metal will ever be used on a large scale is a matter for the manufacturer to decide. It should be possible to make sheet metal basins in sections that can be transported and assembled easily. By stamping these basins out in large quantities at steel mills the greatest item of cost in basin construction—namely, the expense of labor—could be reduced drastically. It is probable that sheet metal would prove a most economical building material. Such faults as a tendency to

buckle and susceptibility to corrosion could be eliminated by factory designers. It may be dangerous, however, to use basins of rustless iron. This metal derives its rust resistance from addition of non-ferrous metals, chiefly cobalt, manganese, and nickel. These substances are apt to be toxic. Consequently,

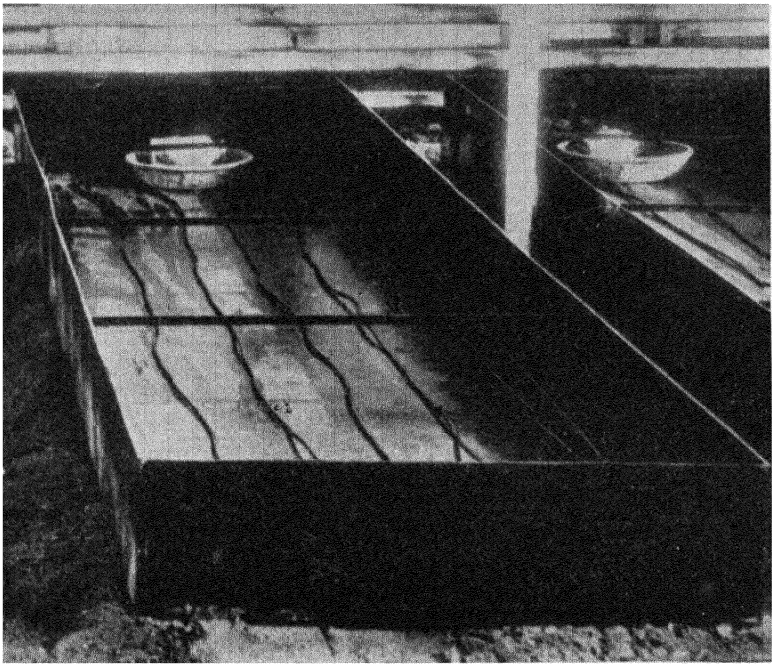

Fig. 3. The first basin constructed from sheet metal. Sides and ends were bent into place by being passed through a brake. Corners were joined by flap and welding. Necessary rigidity was provided by a back seam, and protection from corrosion was provided by coating the interior with quick-drying asphalt paint. The dimensions are 10 feet long by thirty inches wide and eight inches deep. The cables which can be seen lying on the floor of the basin were used for heating the solution electrically.

if you do not know the exact composition of the metal being used, you will be wise in coating it with asphalt enamel. Galvanized iron should never be used unless you are sure that the protective paints or enamels are completely effective. None of those used so far has been long-lived in water. All have had to be re-covered occasionally.

Wooden Basins

Boards of standard sizes are obtainable almost everywhere. Elaborate millwork is not required. Accuracy of dimensions is important as is proper squaring of the ends. Use straight-

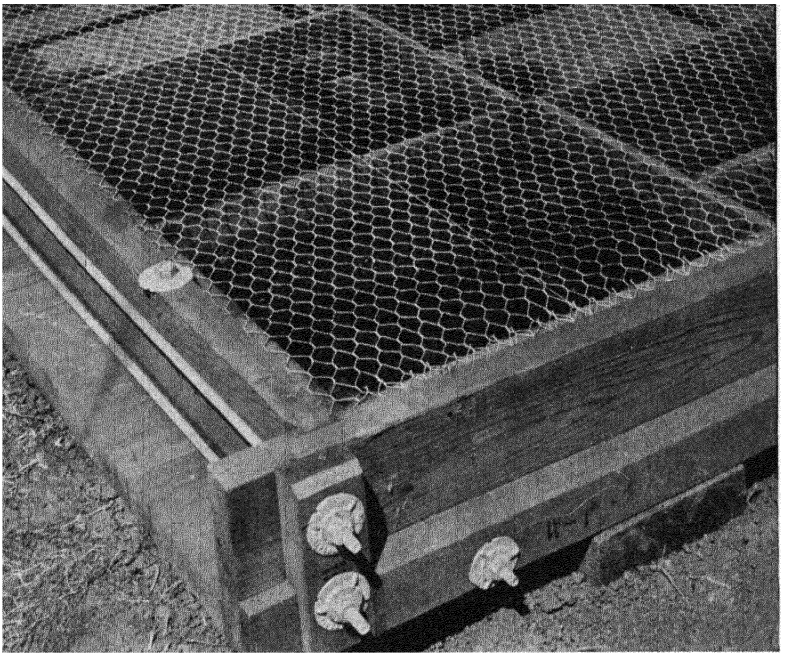

Fig. 4. Section of a wooden basin showing the wire netting in place and the ends joined together by means of tie rods and croze. The basin is of two-inch planking, 18 feet long. The planks are straight-edged. No nails are used. Assembling such a basin consists simply of placing the pieces, inserting twelve tie rods in holes bored for the purpose, and drawing the pieces together. This basin is more substantial than necessary.

edge boards, as tongue-and-groove lumber may not be water tight. They should be as free of knots as possible, though boards with small, sound knots need not be rejected. They may be drawn together by means of tie rods inserted through holes in each piece.

So far experiments have not shown any wood to be toxic. Reports that California redwood cannot be used for basins are

not supported by fact. Redwood was the first wood used in hydroponics. It has always proved satisfactory in every production plant where it has been tried.

Other Basin Materials

Basins are the greatest items of cost in hydroponics. Tests have shown that clay, treated with alkali and then puddled to render it impervious to water, may be the most inexpensive basin material of the future. In one experiment four inches of clay mixed with soda ash were placed in bottomless containers. The clay was puddled and the basins filled with nutrient solution. No leakage was observed during the ensuing twelve months. In other tests plants have been grown successfully in "mud basins" filled with solution. Such containers would not be used for homes or gardens because they do not have the desired neatness.

Consideration is also being given to other materials less expensive than wood, sheet metal, and concrete. Actually, all of those tested will probably find some place in hydroponics. They need not have great strength so long as they are inexpensive and impervious to water. Of the materials now being used, wood probably will be the most economical for large ready-to-assemble basins. Twenty dollars per thousand board feet will usually cover millwork and tie rods on sizable orders.

Basins to Hold Plants for Display

Plants grown for display in the home can be raised to size in individual seedbeds placed over large basins. When they have reached suitable size, they and their seedbeds can be moved bodily to small decorative basins of glass, pottery, or other suitable material. It is hoped that such containers equipped with a small inside shoulder to support the seedbed will soon be on the market. They are now being designed but are not yet manufactured.

Seedbeds

The seedbed is one of the most important features of hydroponic equipment and at the same time one of the most difficult to construct properly. It is designed to perform many duties, or functions, which in agriculture are performed by the soil:

To provide physical support for the plant.

To hold moisture so that it can be absorbed by seeds and by the roots of growing plants.

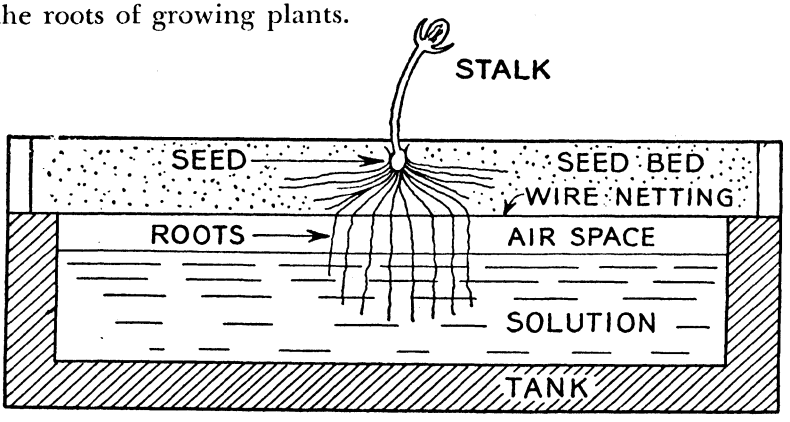

Fig. 5.

To allow air to reach the lower portions of the plant and the nutrient solution below.

To protect the roots from sunlight and excessive changes in temperature, as well as to hold the plant's root crown so that feeding roots are directed into the solution.

To provide mineral plant food and certain organic decomposition products which are necessary for plant life.

Besides serving as a substitute for soil, the seedbed performs useful non-soil functions. By providing a cover for the basin, it prevents the breeding of mosquitoes and the growth of algae in the nutrient solution. Nor can water in the basin become stagnant since it is kept in complete darkness by the matting. *Stagnant* water contains decayed inorganic matter. There are two types of decomposition: (1) that which requires free air, and (2) that which does not. The remedy for the first is to prevent easily decomposable plants—algae—from growing;

that for the second is occasionally to clean the tank of dead roots.

The seedbed partly controls climate in the area immediately adjacent to the growing plant. Normally, we think of climate as represented by the physical properties of the atmosphere; that is, by the temperature, humidity, air velocity, and sunlight prevailing over the earth's surface. These properties change much more rapidly in air than in soil. For example, consider a plant in normal position with roots deep in the ground, root crown just below the surface, leaves and stalk exposed to the air. "Weather" conditions remain practically constant in the root zone, vary only moderately in the surface soil surrounding the root crown, but change considerably from day to night in the air surrounding the leaves and stalk. By studying these natural differences in plant climate we find that the plant, although a unified, living body, is nevertheless made up of parts having different climatic requirements. Hydroponics has severed plant life from its natural habitat—the soil. When held in its proper hydroponic position, the plant has its feeding roots in a basin of nutrient solution, its root crown in an artificial seedbed, and its leaves and stalk in the air. You must make the seedbed duplicate the natural climatic pattern.

Composed of a porous mat of vegetable litter, the seedbed is suspended above the nutrient solution on wire netting fastened securely to a portable frame which rests on top of the basin. Materials are inexpensive and easy to obtain: excelsior, leaf mold, peat, sawdust, wood shavings, straw, chaff, and soil. Green materials, such as lawn clippings, green hay, and weeds, may also be used but not in large quantities, since they may cause harmful fermentation in the bed. Spun glass and other fine materials made from silica have been tried. They apparently have no advantages over vegetable litter except in experiments where insoluble yet porous materials are needed.

Construction of Seedbeds

To the casual eye, construction of a seedbed from the materials mentioned may seem easy. There is more to this opera-

tion, however, than simply piling a mixture of litter on a wire netting. Preparation of the seedbed in hydroponics corresponds in many ways to cultivation of the soil in agriculture. It follows, therefore, that you must exercise the same care in constructing this mat of porous material that the good farmer does in preparing his fields for planting.

Vegetable litter differs greatly from soil. Both are porous, but soil is composed of heavy, very fine particles while litter is light and coarse. Soil is uniform in texture and structure.

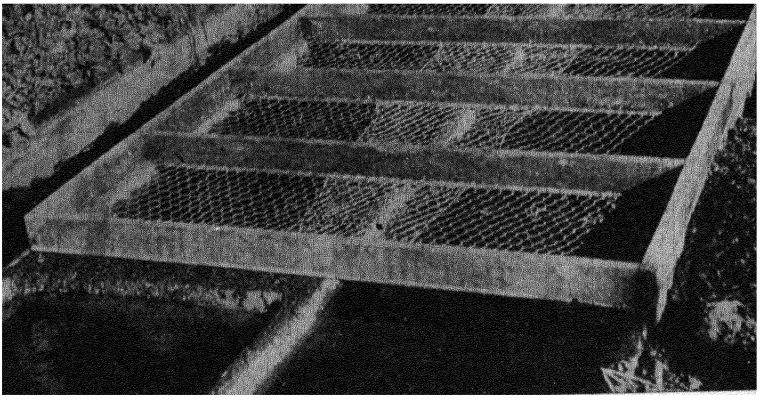

Fig. 6. Seedbed frame constructed to rest on top of the basin. This is a better arrangement than to have the seedbeed mounted within the basin.

Vegetable litter is not. In soil the material in which the seed is sown is the same as that in which the roots grow. But under hydroponic conditions the seeds are sown in a bed having certain properties, while the roots live in another medium—the nutrient solution—which has very different properties. Because the roots must adapt themselves to life in the solution, their structure is markedly different from that of roots growing in soil. Furthermore, the roots in hydroponics are more exposed to natural forces than they are in agriculture. Unless all the factors of plant growth are carefully considered and care taken to provide the best possible environment for growth, hydroponic conditions may be much less favorable than are those of agriculture.

Seedbed Dimensions

Seedbed frames should range from 6 to 12 feet in length and from 2 to 4 feet in width. Beds narrower than two feet will have a limited use. For example, any crop may be grown in the wider seedbeds, but narrower ones are ill-suited to such crops as potatoes and corn. Also, it is harder to maintain ideal growing conditions in narrow seedbeds than in the wider ones.

Hints on Construction

You may have difficulty in determining the amount of lumber you will need. So consider a seedbed 10 feet long by 3 feet wide. This bed will require 41 running feet of one-inch lumber of the desired width—20 feet for the sides, 6 for the ends, and 15 for the cross-supports. The supports keep the frame rigid and prevent the wire from sagging. In this bed five supports will be used, placed twenty inches apart. The bed you actually build may not be of the dimensions quoted here, so remember this general rule: When in doubt, place the cross-supports a little closer together. It has been my experience that people usually do not provide enough cross-supports and consequently have trouble with sagging of the seedbed.

Seedbeds are exposed to more wear and tear than any other part of the hydroponic equipment. The framework to which the wire netting is attached should be as strong and rigid as possible. The use of heavy lumber, however, is not necessary. The desired strength can be gained with lighter materials so long as the frame is properly constructed and braced. For medium-size frames, boards three inches in width are recommended. Larger frames, particularly those measuring more than 3 feet wide by 12 feet long, will require lumber a little heavier. One-inch boards, four to six inches in width, should prove satisfactory. The frames should not be too heavy, since they must be removed about once a year when the basins are cleaned. Small frames, 1 or 2 feet wide by 5 or 6 long, can be built from two-inch boards if a deep seedbed is not required. Any kind of lumber may be used that does not warp easily.

Suitable woods are California redwood, fir, soft pine, and cypress.

Wire netting in several grades and styles of mesh may be obtained from a hardware dealer or, if large quantities are to be used, direct from the manufacturer. Nineteen and 20-gauge wire with a one-inch mesh, called wire cloth by the trade, is rigid, durable, and the most economical for use in seedbeds. It comes in rolls 150 feet long with widths reckoned in multiples

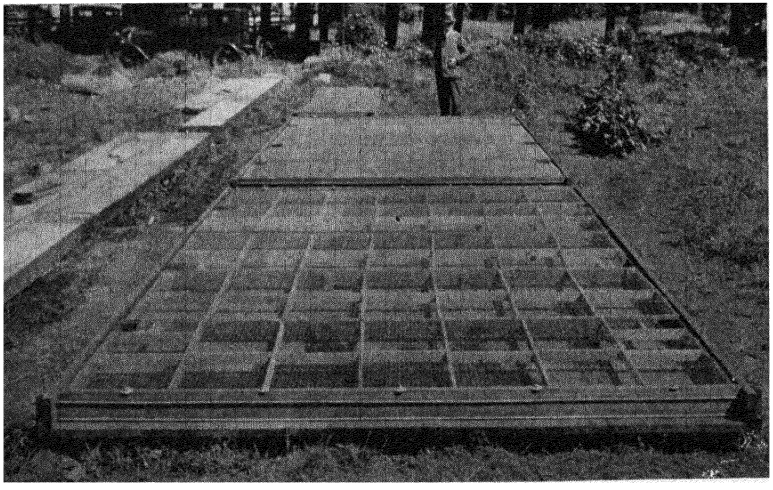

Fig. 7. Two 1/200 acre basins joined together as one unit of 1/100 acre. Seedbed consists of ten frames, each 4 feet wide, 12 feet long, supported within the basin.

of six inches. The netting must be able to support a constantly increasing weight without sagging to the point where the seedbed touches the nutrient solution. Galvanized wire should be coated with quick-drying asphalt paint or enamel manufactured for iron to forestall corrosion and also to prevent zinc in the wire from dissolving into the solution. Use paints with volatile solvents, such as gasoline, carbon bisulfide, or turpentine. Paints with oil solvents should not be used. A concentration much exceeding two-tenths to three-tenths parts of zinc per million of solution will render the liquid toxic to plants feeding from it. Wire of less than one-inch mesh should not be used

except when fine litter must be supported. In such wire the area of zinc exposed, and thus the danger of an excess being dissolved into the solution, is greater.

In securing the wire to the frame, nail down one end first, taking care that the mesh is parallel to the end of the frame, then stretch the wire to reasonable tautness and nail down the other end. Nail the sides last. The seams (that is, the outside double strands) of the wire should be fastened to the sides of the frame. To obtain the proper tautness, stretch the wire by pulling it from one side to the other after the ends have been nailed down. There will be little give to the wire when it is stretched in this way.

After the netting has been firmly secured, a layer of straw, wood excelsior, or other coarse material is laid upon it. This layer must not be so deep or firmly matted that it interferes with root penetration. Such crops as daffodils or tulips would have difficulty in pushing their roots through a one-inch mat of very fine excelsior. Adjustment of the seedbed according to the penetrating power of certain crops will be discussed in later chapters. You need make this bottom layer only thick enough to prevent finer materials from falling through into the nutrient solution. A mat of wood excelsior, one-half to one inch thick, should be deep enough. It will compress and be much thinner when the rest of the litter is added on top. Soak the excelsior with water before putting it on the netting. If dry, brittle material is used, some of it will drop through into the basin. When straw is used, a deeper layer, approximately two inches thick, is necessary. On large basins from which strong and vigorous crops are to be grown, you may even use shredded cornstalks interspersed with straw. These coarse materials are inexpensive and well-suited to such plants as corn, potatoes, and tomatoes. They are not very neat, however, and should not be used with small, fine-rooted vegetables or flowers.

Water Capacity

Consider the water-holding capacities of the materials used in the seedbed. The question is not how much water they can

hold but how they hold it. They must be porous enough to absorb water in large quantities by capillary or surface action so that it saturates the air around the root crown and is also available for the germination of seeds and absorption by roots. This is the way in which water is held by a moist, well-drained soil. The material must not hold large amounts of free water completely surrounding the seeds, or plants, and exclude all air, for plants, like humans, must respire. Should the seedbed become so wet that it cuts off the flow of air to the roots and root crown, the plants will drown. Air-holding capacity is thus very important. If there is too much water, there is not enough air and vice versa.

Faults of Wet Seedbeds

Seeds of warm-weather crops, such as cotton, corn, and melons, germinate too slowly if planted in a seedbed that is too wet. These seeds require high temperatures to start their growth. Excess water in the litter will force temperatures below the point desired. It is common practice to soak the seedbed when seeds are first planted, but it should not remain saturated longer than twelve hours after planting. Water heats very slowly and the soaked litter will not warm up as rapidly as desired. For this reason warm-weather crops may not do so well in the seedbed as in the soil during cool seasons. On the other hand, they may find the seedbed a more favorable environment during warm weather, when soil temperatures often rise too high.

Excess water in the seedbed may also prevent development of feeding roots by the plants. For example, practically none of the upland crops will grow if their root crowns are submerged. Under these conditions roots simply will not develop.

A seedbed which is too wet is like a water-soaked sponge. When you press the sponge, water runs out. When you relax your grasp, the water remaining in the sponge is held largely by capillary attraction. Therefore, to determine whether a seedbed is too wet, simply squeeze or press it with all your strength. If water runs out, the bed is too wet. Farmers can

tell whether soil is too wet to plow or cultivate simply by looking at it and feeling it.

Dry Seedbeds

Seedbeds which are too dry fail to provide enough moisture. They allow root crowns to become too hot when sunlight is intense and too cold when air temperatures drop to low levels. The root crown is normally located in the upper layer of the seedbed. Because the litter is a poor heat conductor, the warmth from sunlight is not transmitted readily from the top to the bottom of the seedbed. Thus, the top layer absorbs heat quickly and holds it. This concentration of heat in the top layer may dry up the root crown. On the other hand, if water is supplied to the litter in sufficient quantities, its high specific heat will make the seedbed a most desirable environment for plants in hot weather, for water, as pointed out above, can absorb large amounts of heat without rising greatly in temperature. By virtue of this fact, it protects the seedbed against heat in a manner which cannot be duplicated in the soil. Air, a poor conductor of heat, provides additional insulation between the seedbed and the nutrient solution.

Plants which have the power to penetrate large quantities of litter also receive greater protection from unfavorable climate when grown in a seedbed. These plants can be rooted deeper (and their seeds planted deeper) in the seedbed than in soil because of the lighter weight of the materials used.

Choice of Seedbed Materials

By using coarse materials, such as straw and excelsior, you can assure an abundance of air to the seedbed, but these materials may not absorb enough moisture. Fine materials, such as soft wood sawdust, absorb too much water and pack together so tightly that air is excluded. You must combine these two types—the coarse and the fine—so that they blend into a litter than can absorb sufficient moisture yet does not hold large amounts of free water which keep out the air. When growing strawberries, it is wise to keep the surface of the seedbed dry

by placing a layer of material of low water-holding capacity such as rice hulls on top of the other litter of high water-holding capacity surrounding the root crown.

Excelsior is a highly useful material. Wood shavings also are good seedbed material, possessing more resistance than excelsior. Both can be purchased in different grades of fineness, the finest excelsior being known as "wood wool." Straw and hay are substitutes for excelsior but do not form so compact a matting. Straw, largely composed of cellulose, decomposes more quickly than wood products. Broken cornstalks can be used where a deep, well-aerated bed is required. They do not decay so quickly as straw and can be used for such crops as potatoes. Corn ensilage is another good material. Peat and sphagnum moss have great water-holding capacity and suffer little change with age, but usually require blending with materials of low water-holding capacity.

Some materials, particularly new sawdust and wood shavings, may contain toxic substances. These will have no effect on crops which send their growing roots quickly into the nutrient solution. They do present a danger, however, to such crops as pansies, snap-dragons, and stocks, which have shallow and lateral roots. To safeguard these plants, put their seed next to non-toxic litter so that a layer separates them from the harmful material.

Nutritive Action of the Seedbed

The seedbed acts as a nursery for young plants, feeding and watering them until they have established themselves in the nutrient solution. Even then they are not completely independent of the seedbed. They draw upon it constantly for moisture and even for food. The transition from complete to only partial dependence on the seedbed is necessary for the health of most vegetables. The bed cannot supply them with enough food and water, nor is it large enough to permit proper expansion of the root systems. However, continued provision of food and water by the seedbed is indispensable to such shallow-rooted crops as pansies, begonias, and snap-dragons among the flowers, and cabbages, potatoes, and melons among the

vegetables. Addition of nutrients to the bed also encourages tall crops, such as corn and tobacco, to develop lateral roots, which give them added support. These crops should be planted close together so that the lateral roots will intertwine and the plants support each other.

To add nutrients to the seedbed, simply scatter them on top of the litter. Usually, moisture in the seedbed will then dissolve them and carry them down to the root zones. If the seedbed is dry, sprinkle it with water. Because the litter has much less absorbing and fixing power than the soil, small applications of fertilizer are more effective in hydroponics than in agriculture. Conversely, large applications of plant food can be harmful in hydroponics where they would not be in soil because large portions would be absorbed by the clay. More specific instructions as to the amount of plant food to be added are included in the chapters dealing with specific crops.

Use of Soil Beds

If you are relatively inexperienced in growing plants, you may find soil a better medium for germinating certain seeds than the litter seedbed. This is more a question of convenience than anything else. Conditions favorable to germination of practically all crops can be created in hydroponics. However, the coarse vegetable matter is subject to greater variations in temperature, moisture, and air conditions than is soil. So you may have trouble in germinating certain seeds in the seedbed. Special care need not be taken in moving soil seedlings, since their soil-formed roots will die and new ones, adapted to the different environment, will appear as soon as they are established in the nutrient solution.

Decay of Seedbeds

After the seedbed has been in use for some time, it will begin to decay. This should cause no alarm, for it is a natural process and produces organic decomposition products needed by the plants. Woody materials are the last to decompose. Straw

decays more rapidly and green materials most quickly of all. There is no necessity for building each seedbed out of new material. The old litter can be used repeatedly. However, there will always be losses from weathering of the litter, particularly if too much green material is used, and new litter

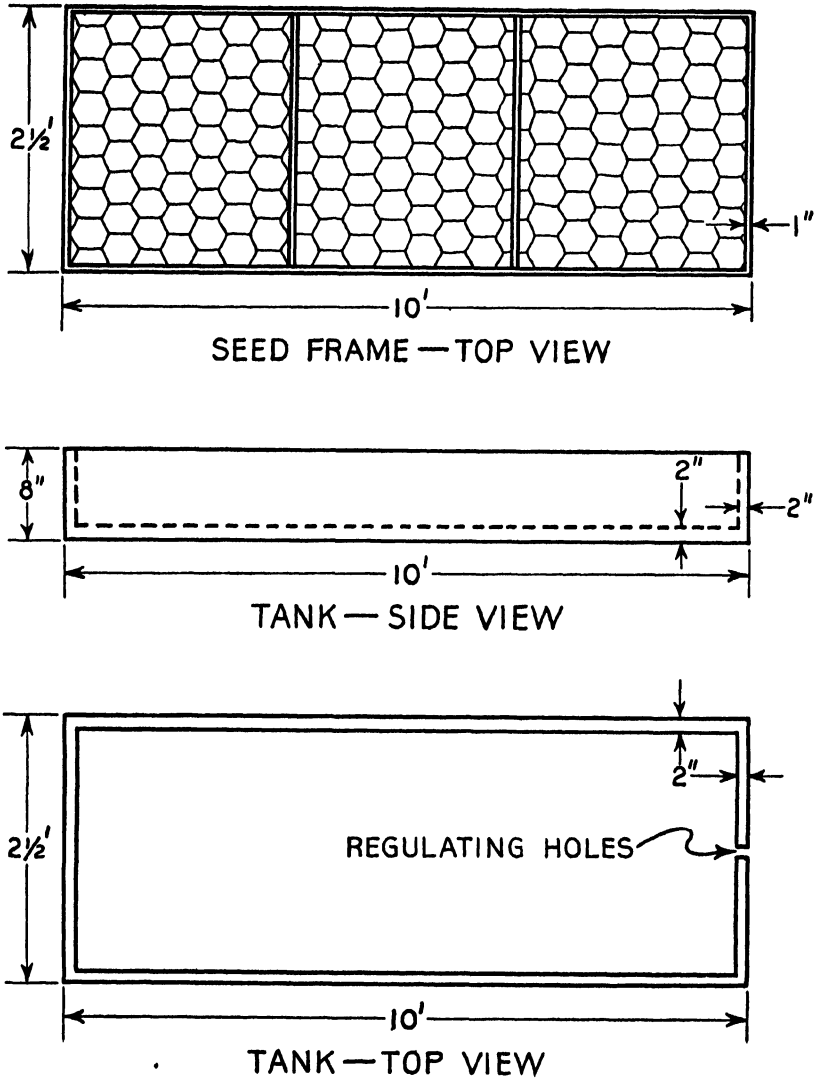

Fig. 8a,

must be added from time to time. For example, new excelsior and straw will be needed to re-cover the wire netting. Fresh material being added to the litter should usually be placed on top of the old, for it may contain harmful plant products. These toxic substances are oxidized and rendered harmless

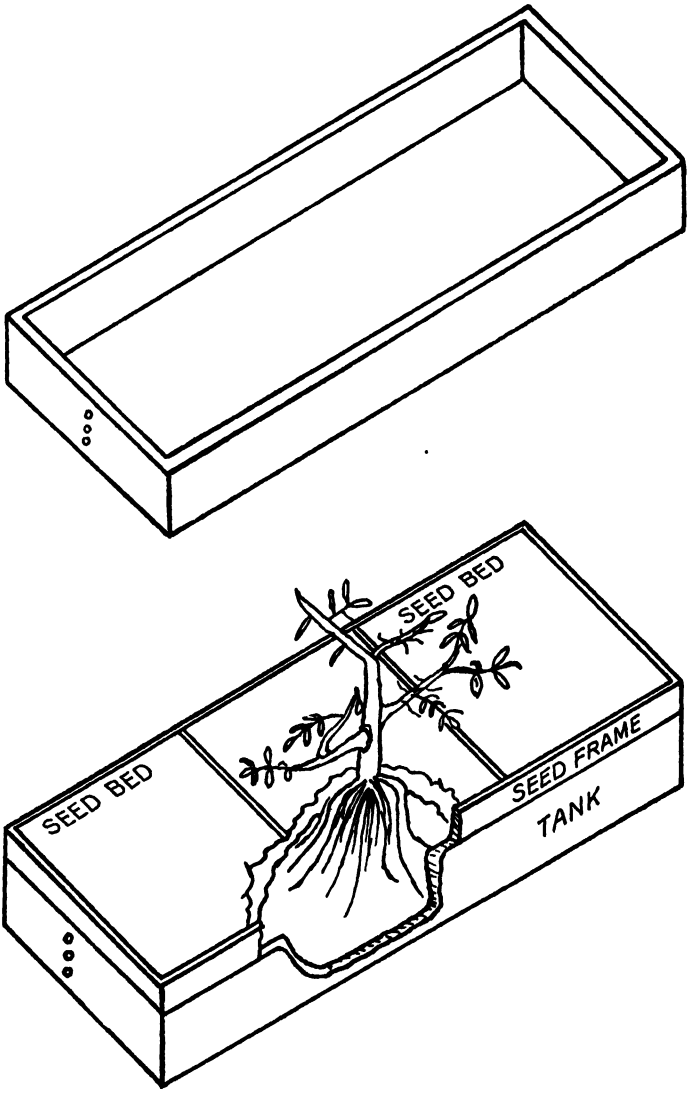

Fig. 8b.

when exposed to air and sunlight. I have not found California redwood sawdust and wood shavings to be any more toxic, notwithstanding reports to the contrary, than other woody substances, though they may discolor the plant roots.

Directions for building the seedbed cannot be given as simply as A, B, C. The soil is supplied by nature with all the factors needed to encourage plant growth, and the duplication of these in the seedbed is a task of no mean proportions. You should be able to construct a suitable seedbed without too much difficulty. The main requirements, aside from the guiding information offered in this chapter, are caution and careful thought. Failures usually result from some small and simple mistake which is easily found and corrected. When properly constructed and cared for, the hydroponic seedbed will fulfill all expectations as a favorable environment for growing plants. Ideal conditions for plant growth can be maintained more easily and with less manual labor in vegetable litter than in soil, if you handle your materials wisely.

In practically all cases soil can be used instead of sawdust and other fine vegetable litter for filling the interstices of straw and excelsior placed on the wire netting. The use of soil beds is described in the chapter on Sand Culture. A mixture of soil and vegetable litter is usually the most serviceable and economical material for seedbeds. It provides the advantages of both soil and hydroponic properties in crop production.

CHAPTER THREE

Nutrient Solutions

Sources of Plant Food

Pure chemicals are not needed in hydroponics any more than in agriculture. Those used in laboratory experiments and manufactured to meet the United States Pharmacoepia (U.S.P.) requirements are more refined and costly than necessary. Some land fertilizers and the chemicals manufactured for technical purposes in manufacturing are suitable sources of plant food. They are widely distributed as natural resources. At present no companies are producing chemicals specifically for hydroponic use with a full analysis of their impurities. The various chemicals do not have the same impurities, however, and, since the complete mixture contains eleven different elements, the chances are that they can be blended together very easily. As a result, fairly crude material can be used.

It has already been explained that plants require rather large amounts of six different substances—nitrogen, calcium, magnesium, phosphorus, sulfur, and potassium. Five other elements—iron, zinc, copper, boron, and manganese—are needed in very small amounts.

Sources of Chemicals

Potassium and nitrogen are supplied in the form of potassium nitrate—KNO_3—also called nitrate of potash or saltpetre, but Chile saltpetre (sodium nitrate) cannot be used in its place.

The grade used as land fertilizer is imported, about 95 per cent pure, and retails at from sixty to seventy-five dollars per ton. The usual impurities in the imported product are calcium and potassium carbonates, which are not harmful. Potassium nitrate is the most expensive major chemical used in hydroponics and constitutes from one half to two thirds, by weight, of the complete mixture.

Magnesium in its most economical form is found in the sulfates known as Epsom salt and kieserite. Kieserite —$MgSO_4 \cdot H_2O$—is the less expensive of the two, in its crude form costing at the most twenty dollars per ton while Epsom salt—$MgSO_4 \cdot 7H_2O$,—containing only half as much magnesium, is quoted at around forty dollars per ton. Natural deposits of magnesium salts and minerals are widely distributed. Some are so pure that they can be used for land fertilization, and with a small amount of processing are also suitable for hydroponics.

A land fertilizer, treble super phosphate, a mixture of $Ca(H_2PO_4)_2$ and SiO_2, is the principal source of calcium and phosphorus. It is composed principally of a compound called monocalcium phosphate which in its pure state contains 60 per cent water soluble phosphorus pentoxide—P_2O_5. In price treble super phosphate ranges from forty to forty-five dollars per ton. Much of this fertilizer is manufactured by treating natural tri-calcium phosphate with acid. Its chief impurity is a non-toxic silica. However, it may contain fluorine derived from the natural rock or arsenic absorbed from the acids used in processing. These two impurities, particularly arsenic, are not desirable.

In localities where the water contains a large amount of calcium, two other compounds are used to provide phosphorus: phosphoric acid and ammonium phosphate. The technical grade of the acid is about 50 per cent pure H_3PO_4 and may be purchased for approximately one hundred and twenty dollars per ton. Ammonium phosphate is a land fertilizer manufactured in two different forms: mono-ammonium phosphate —$NH_4H_2PO_4$—and di-ammonium phosphate—$(NH_4)_2HPO_4$.

Prices for these products run from fifty to sixty dollars per ton, respectively.

The land fertilizer grade of calcium nitrate, $Ca(NO_3)_2 \cdot H_2O$, may be used as a supplementary source of calcium or nitrogen. It sells for about thirty dollars per ton. Good nutrient solutions can be made without it; however some experimenters do use it as a chief source of nitrogen. Don't use large amounts of it in localities where the water naturally has a high calcium content.

Sulfuric acid—H_2SO_4—is another major chemical, constituting from 5 to 30 per cent in weight of the complete plant food mixture. The percentage varies according to the nature of the water supply. Various processes are employed to make this substance by oxidizing sulfur or sulfur compounds. The most economical of these methods produces an acid possibly unsuited for hydroponics because it contains arsenic, lead, and selenium. In certain forms these three are among the most toxic materials known, though up to the present they have caused no difficulty. If large quantities of the acid are required, however, they may attain toxic concentrations. Consequently, you will be wise in using the technical (66 Baume) grade of sulfuric acid, costing about twenty dollars per ton. This substance has exerted a most profound influence on the fertilizer industry. It is used extensively today. Market demand for it is recognized as one of the most sensitive indicators of business conditions. It has never been classed as a fertilizer, however.

All the chemicals mentioned as being needed in small quantities are contained in crude but usable industrial materials. The common washing powders containing sodium borate provide boron. Practically any crude salt of copper, zinc, and manganese can be used to supply these metals. The soluble sulfates and chlorides offer a most inexpensive source of iron, but because much of it is made from scrap iron, it might contain too much copper, zinc, and other metals. It is necessary to know the amount of impurities, if such a grade of iron salt is used, and to make proper allowance in the formula.

Cost of Chemicals

The price quotations given above convey only a general idea of the cost of basic plant food sources. They represent manufacturers' or wholesalers' prices for chemicals handled in large lots and have little bearing on the retail price of chemicals sold in small packages. The latter are usually priced several times higher than their actual value. Large growers will undoubtedly buy at manufacturers' prices. Their complete hydroponic mixtures, ready to use, will cost from fifty to sixty dollars per ton, or from two and one-half to three cents per pound, depending upon the composition.

You may purchase the chemicals in their basic form and mix them yourself. The dry substances usually come in hundred-pound packages filled at the place of manufacture. The only exception to this rule is imported potassium nitrate which is shipped in 220-pound bags. Liquids, such as sulfuric acid, are delivered in glass carboys or non-corrodable drums. Large quantities of chemicals can be mixed with a power concrete mixer; smaller amounts by hand or with the same equipment used in preparing mortar on light construction jobs. The mixture may be stored in wooden boxes and bins, or left on a pile, covered, to protect it from rain. Do not use cloth or fiber bags for storage, as the acid in the mixture will cause them to disintegrate.

At present no complete mixtures, as designed by the originator of hydroponics, are on the market. Ultimately, they will be available from reputable concerns at honest prices. The public has already been victimized by promoters selling mixtures which cost them less than five cents per pound for from three to five dollars per pound. There is no reason why hydroponic salts should be more expensive than the common grades of land fertilizer.

Distribution of Complete Mixtures

The preparation and distribution of complete mixtures for those who do not need large quantities of chemicals should

be handled through a central agency. The most economical method would be to have chemicals mixed in large lots, according to the composition of the local water supply, by the chemical or fertilizer industry. They could then be weighed out in small portions or sold as packaged goods. The most efficient small package would probably be a three-pound size.

Whether this plan is finally carried out will depend largely upon whether or not complete mixtures are classified legally as fertilizers. Actually, the name "fertilizer" is not a happy one for hydroponic mixtures. Another should be found. For "fertilizer" has a distinctive meaning in agriculture which does not apply in hydroponics. All chemicals suitable for hydroponics can be used as land fertilizers but the reverse of this proposition does not hold. In soilless crop production the solution properties of the chemicals, as well as their nutritive value, must be considered. The term "fertilizer" with its present familiar connotations is an ill-suited designation for chemicals for hydroponic use.

Laws covering the sale and transportation of fertilizers are inadequate to prevent fraud in the distribution of hydroponic chemicals. State regulations require that consignments of fertilizers state clearly the percentage of nitrogen, phosphorus, and potassium contained in the compounds. The relative merit of hydroponic mixtures is not determined by the percentage of any one, or all, of these chemicals they may contain. For this and the other reasons given above, it becomes obvious that to protect the public interest chemicals sold for use in hydroponics must be subjected to a separate body of regulations.

The Nutrient Solution

The elements necessary for plant growth may be segregated into three groups. In the first are those used in large quantities and of which the plant will absorb an excess if it is available. These elements are not toxic even in very high concentrations. In the second group are those used in fairly large quantities but absorbed only according to the plant's needs. Third are elements which will prove toxic if their concentration in the solu-

tion exceeds a fraction of a part per million. The elements of the first group are potassium, nitrogen, calcium, magnesium, and phosphorus. Sulfur is the only element in the second category. The third is composed of boron, iron, manganese, copper, and zinc.

These categories suggest that so long as care is taken in providing the third group of elements, the others may be supplied in any combination. Various formulae used in laboratory experiments have been compounded on this principle and bear no resemblance to the composition of plants. For example, in some there is more phosphorus than nitrogen and several times more calcium than potassium. These relationships are markedly different from those in plants. Seedlings can be grown for a short time with such mixtures but, if the plants are to develop normally to maturity without further adjustments of the nutrient solution, the formula must be based upon knowledge of plant composition from the very start.

From our knowledge of selective absorption we might also get the idea that salt proportions in the solution are unimportant since the plants will take what they want and leave the rest. On the other hand, from the view that the plant's composition mirrors the correct proportion of the various salts in the solution, we might draw the conclusion that only one basic formula can be used. Actually, both these factors operate in hydroponics. The formula alone cannot determine the plant's composition for this is also influenced by the conditions under which it grows. The formula must represent a compromise between two opposing conditions. If environment and climate are ideal, however, the formula which represents most accurately the plant's composition will be the most efficient.

Taken from their categories and listed according to amounts of each included in plant composition, the elements are in descending order: nitrogen, potassium, phosphorus, calcium, magnesium, sulfur, iron, manganese, boron, zinc, and copper. This is only an approximate order, for any of the elements may be shifted one or two places. For example, some low-protein crops use more potassium than nitrogen. Others use more potassium than nitrogen under one set of conditions and then reverse the

order under another. Thus, it is more logical to consider the important elements in sets of twos so far as the required quantities are concerned. This is because the nutrients are supplied in compounds containing two elements each: (1) potassium and nitrogen, (2) calcium and phosphorus, and (3) magnesium and sulfur. The other substances in the list cannot be treated in this way, for the quantity relationship between them is not so apparent. To supply the major elements in twos, potassium nitrate, calcium phosphate, and magnesium sulfate may be used.

Another way of arriving at the selection of chemicals needed is to find out what effect the absorption of any one of them by the plants will have on the reaction of the solution. It has been shown in the chapter on water culture that salts dissolved in water break up into particles, or ions, carrying negative and positive electrical charges. If the plants take up more of the negative than of the positive ions, the solution turns alkaline. If more of the positive ions are absorbed, it turns acid. Thus, the elements of opposite sign must be paired together so that absorption of one will not leave an excess of the other. When this is taken into consideration, potassium nitrate, calcium phosphate, and magnesium sulfate again prove to be the chemicals which should be used. Magnesium phosphate and calcium sulfate might be used with equally good results in place of the last-named chemicals. However, magnesium phosphate is relatively hard to obtain from ordinary sources, for it is not manufactured in large quantities.

The proportion of each element in the nutrient solution is determined not by how much the plant will absorb but how much it actually needs. The key to the plant's actual requirement is found, as I have said, in its own composition when it is grown in such a way that the maximum benefit is obtained from all the elements provided. The elements should be provided in accordance with their relative percentage content in the plant considered as an aggregate of parts having differing compositions.

Those elements absorbed most readily by the plants must be restricted in quantity relatively to those absorbed more slowly.

For example, nitrogen is used normally in larger quantities than any of the other elements and must be provided in larger amounts in the solution. However, as it is absorbed more readily, it must be restricted to some extent, for excessive absorption of one element will repress absorption of the others. To illustrate, let us consider a plant which will absorb ten ions of various elements during a given period of time. This is the maximum amount which it can absorb during the period. Of the ten ions available, five are positive and five negative. Three of the negative ions are nitrogen. This leaves but two ions to be provided by the other negative elements. Thus, if there is an excess of nitrogen present, the plant will seize upon this readily absorbed substance, take in perhaps four ions of it, and only one ion of another negative element. In this way, nitrogen crowds out other elements which are also needed. Also, by decreasing the amount of nitrogen in the solution we may force the plants to take in more ions of other negative nutrients. Thus, to a certain degree the elements must be provided inversely to the readiness with which they are absorbed.

The essential principle may be stated thus: The elements should be provided in the solution in their proportion in the composition of the plant being grown and each element in quantities inversely to the readiness with which it is absorbed. Your responsibility is to strike a balance between these two factors.

More concretely: Can the entire quantity of each element required to grow a crop to maturity be supplied in the solution at the start? The answer is: Yes, if the rate of absorption for each element can be maintained in the original proportions throughout growth. Unfortunately, this does not always happen. Other factors beside the concentration of an element in the solution may influence the rate at which it is absorbed. For example, take nitrogen. If you wish to add to the solution at the very start all the nitrogen required to bring the crop to maturity you must supply it in such a chemical combination as to prevent its being absorbed in excess. Excess is not merely a matter of the total amount absorbed by the plant, but one of the total amount absorbed in relation to other elements.

Nitrogen is normally absorbed very rapidly by plants, but when supplied as potassium nitrate, which is conducive to good growth, excess is precluded by the absorption of potassium. When all the nitrate required is supplied this way the solution will contain excess potassium, but it will not change in reaction sufficiently to require adjustment, which would be the case if it were supplied in other forms irrespective of the potassium concentration.

Testing for Nitrogen and Phosphorus

Plants reduce the amounts of nitrogen and phosphorus in the solution to lower levels than those of the positive elements potassium, calcium, and magnesium. If the solution is properly compounded, you can determine by testing for the amounts of nitrogen or phosphorus present whether or not the liquid contains sufficient nutrients of all kinds. If the number of nitrogen ions is about equal to the number of potassium ions, the plant will not absorb an excess of nitrogen even though the concentration of this element is high. And, when the minimum quantities of nitrogen and phosphorus are provided, the plant will automatically absorb enough of the other major elements to meet its needs. The solution should be so compounded that nitrogen and phosphorus are exhausted at the same time. Then, when they are properly paired with potassium and calcium, a test for either one of these negative elements will tell if enough of each is present.

Once the cultural technique has been mastered, tests for nutrients in the solution will not be necessary, as you can estimate the amount in the basin by the growth of the plants. Those who want to follow the change in the quantities of nutrients in the solution can analyze samples at intervals of growth. There are simple methods requiring but a few drops of sample, but those that require larger amounts are better suited for making calculations if one is not familiar with the principles of chemical analysis.

Take a sample of about a tenth of a pint, or a tenth of a quart, and evaporate it to dryness. Add several drops of

phenol-disulfonic acid—enough to moisten the residue, but not an excessive amount. Dilute it with water to its original volume, then add strong ammonium hydroxide or lye solution to neutralize the acid. A yellow color denotes nitrate. Prepare the standard in the same way with a sample from which plants have not absorbed nutrients. With proper dilution you can observe differences in tints and make calculations.

To test for phosphorus add, to a sample heated to 150 degrees Fahrenheit, 20 c.c. of ammonium molybdate reagent (prepared for phosphorus). The element will precipitate as a yellow compound. Accurate estimation of the amount of yellow precipitate requires further chemical reactions, but you can gain a fair idea by noting the quantities of precipitate in each sample, using the original solution as a standard.

The Basic Formula

The author's basic formula for laboratory use with pure chemicals and pure water is given in Table I. This formula includes only the major elements. The same formula in parts per million is given in Table II.

TABLE I

Basic Formula with Pure Water and Chemicals

Chemical	*Molecular Weight and Grams per Liter*	*C.C. of Mol. Solution per Liter Nutrient Solution*	*Milligrams of Salts per Liter Nut. Sol.*
KNO_3	101	10	1,010
$Ca(NO_3)_2$	164	1	164
$Ca(H_2PO_4)_2$	234	1	234
$MgSO_4$	120	1	120
		13	1,528

The table of molecular weights offers a means of comparing different chemicals. It gives the relative differences in weight between the molecules of the various elements. The quantities of each chemical per liter of water as given in Table 1 all represent the same number of molecules. By taking ten cubic centimeters of potassium nitrate and one each of the other

three chemicals listed, plus 987 cubic centimeters of water to make a liter, you obtain a solution containing ten times as many molecules of potassium nitrate as any one of the other three. In weight, however, the proportion would be much different. The amount of potassium nitrate added would weigh only about six times as much as the calcium nitrate added, four times the calcium phosphate added, and about eight times the magnesium sulphate added.

TABLE II

MILLIGRAMS PER LITER, OR PARTS PER MILLION, OF ELEMENTS IN NUTRIENT SOLUTION

Postive Elements	*P.P.M.*	*Negative Elements*	*P.P.M.*		*P.P.M.*
Potassium	390	Nitrogen	168	Nitrate	744
Calcium	80	Phosphorus	63	Phosphate	190
Magnesium	24	Sulfur	32	Sulfate	96
	494		263		1,030

Thirteen cubic centimeters of these solutions per one liter of water will make a solution containing 1528 parts per million of dissolved salts. About one third of this quantity is due to positive ions and two thirds to negative ions. However, if considered in terms of weight of elements only, the positive substances constitute 494 and the negative 262 parts per million, oxygen not being included.

The ionic ratio of the principal pairs of elements of opposite charge are: for potassium-nitrogen, 10 to 12; calcium-phosphorus, 1 to 1; and magnesium-sulfur, 1 to 1. The ratios of the principal positive elements are: potassium-calcium, 10 to 2; and for the principal negative elements: nitrogen-phosphorus, 12 to 2. The formula is designed to have the plants absorb about six or seven times as much nitrogen as phosphorus, and more nitrogen than potassium, but not exactly in the formula ratio, because nitrogen is absorbed more readily and the ratio will be different inside the plant.

The molecular concentration of this solution is .013, and its osmotic pressure is estimated at about seven tenths of an atmosphere. The average molecular weight of the four salts

used is 117. In order to obtain an approximation of the molecular concentration from a known concentration in parts per million, simply divide the latter number by 117. Changes in the combinations of salts will naturally change this number. The practical formula given in Table III is essentially that of Table I reduced to ordinary measurements.

TABLE III

PRACTICAL FORMULA DERIVED FROM TABLE I
(Referred to in this book as the "basic formula.")

Chemicals	*Quantities*	*Per Cent of Total*
Potassium nitrate	40 pounds	54.2
Calcium nitrate	7 pounds	9.5
Treble superphosphate	10 pounds	13.5
Epsom salts	10 pounds	13.5
Sulfuric acid*	5.4 pounds or three pints	7.3
Iron sulfate	1 pound	1.4
Manganese sulfate	2.5 ounces	.2
Borax	2.0 ounces	.17
Zinc sulfate	1 ounce	.08
Copper sulfate	2/3 ounce	.06

The practical formula is essentially that of Table I translated into terms of weights and proportions. In the right-hand column of Table III you will see that the numbers are carried out to one or two decimal places. In practice, round numbers, are used for these percentages. The table is based on the weights of pure chemicals. The cruder chemicals actually used in practical hydroponics are not weighed with such accuracy.

The proportion by weight of the chemicals in Table III is different from that in Table I. This difference rises from the fact that in Table III the molecules contain water, which is considered a part of them. Thus, calcium nitrate is $Ca(No_3)_2 \cdot H_2O$, molecular weight 182; treble superphosphate is about two-thirds monocalcium phosphate, or $Ca(H_2PO_4)_2 \cdot H_2O$, molecular weight 252; and Epsom salt is $MgSo_4 \cdot 7H_2O$, molecular weight 236. By weighing out the quantities in the same proportions given in Table III you will secure substantially the molecular ratios given in Tables I and II. Use the same proportions whether you prepare a pound or a ton of the complete nutrient solution.

* Amount required for natural water containing about 200 p.p.m. solutes. Use two pints for water containing 100 p.p.m. solutes and still less for purer water.

Three-Salt Combinations

The practical formula given above is the original one used in the first hydroponic experiments and in the first commercial hydroponicums. It is important that the physiological merits of this formula be not overestimated. Good nutrient solutions can be made from other salts. In fact, any one of the three-salt combinations shown below will supply all of the major elements required and has been used successfully for water culture.

(I)	(II)	(III)	(IV)	(V)	(VI)
KH_2PO_4	K_2SO_4	KNO_3	K_2SO_4	KNO_3	KH_2PO_4
$Ca(NO_3)_2$	$Ca(NO_3)_2$	$Ca(H_2PO_4)_2$	$Ca(H_2PO_4)_2$	$CaSO_4$	$CaSO_4$
$MgSO_4$	$MgHPO_4$	$MgSO_4$	$Mg(NO_3)_2$	$MgHPO_4$	$Mg(NO_3)_2$

The names of those chemicals listed above which have not hitherto appeared in this book are: KH_2PO_4, potassium dihydrogen phosphate, also known as primary or mono potassium phosphate; K_2SO_4, potassium sulfate; $CaSO_4$, calcium sulfate, or, if it contains water, gypsum; $MgHPO_4$, secondary magnesium phosphate.

A simple formula that applies to all six of the three-salt combinations shown above is: one-third ounce of each chemical per cubic foot of water together with a trace of the minor elements. If soil or decomposed litter is used for seedbeds, you might not have to supply the minor elements. Other proportions than this one would be more efficient, but different for each combination. This formula, having equal amounts of each chemical by weight, possesses the advantage of working equally well no matter which of the three-salt combinations you desire to use, provided you do not use distilled water, which might make the solution too acid with such large proportions of chemically pure $Ca(H_2PO_4)_2$.

Proportions in Three-salt Combinations

For the sake of determining what are the most efficient three-salt combinations, let us consider the following analyses of some of the different ones.

1. Combinations II, III, IV, and V permit nutrient solutions in which potassium and nitrogen are kept equal and both in greater amounts than any of the others.

2. Combinations I and VI do not permit solutions in which potassium could be present in larger amounts than phosphorus, but by addition of potassium sulfate, the ratio between these two is changed.

Magnesium nitrate, magnesium phosphate, and potassium phosphate can all be obtained from chemical supply houses, but probably will be too costly to use as sources of plant food.

Some of the combinations discussed were first used by Dr. B. E. Livingston of Johns Hopkins University. One hundred and twenty-six different nutrient solutions were made from these combinations and tested by the author under different temperatures at the Laboratory of Plant Physiology at Johns Hopkins University. The data obtained proved of great value in pointing the way for the development of hydroponics.

Preparing the Mixture

In preparing the practical formula of Table III, first weigh out the treble superphosphate and Epsom salts. Add the required amount of acid and mix. The rest of the chemicals may then be added and the whole mass mixed thoroughly together. The mixing will be easier if none of the chemicals are in lumps. Some of the crude chemicals do form lumps if they are stored for long periods before use. They must be pulverized before mixing. However, they need not be in such a fine state as the minor elements, which must be pulverized in order to obtain a uniform distribution.

The acid is added to the treble superphosphate and Epsom salts first to reduce the fumes. The mixing should not be done in any container with which the sulfuric acid will react to form toxic substances. Wooden boxes are suitable and, if small quantities are being mixed, glass jars. If the acid were mixed first with the nitrates, fumes would be given off. The concentrated acid will not react with a metal shovel but will if it is diluted with water. The chemicals should be as dry as possible,

for the action of the acid on water will also greatly increase the fumes. Mixing should be done in the open and in a cool place. Stand to windward to avoid inhaling any fumes. After the material has been thoroughly worked, pass it through a screen with a 3/8 inch mesh. It can then be stored in wooden boxes but should not come in contact with galvanized or copper containers.

One pound of the mixture added to 125 gallons (1,000 pounds) of water would give a concentration of about 1,000 parts per million, if all of it went into solution, which is not the case. This nutrient solution is about .008 molecular concentration with an osmotic pressure of about four tenths of an atmosphere. With waters of relatively high purity, one pound of salts gives the desired concentration and chemical reaction to the solution. But, since pure waters will hardly ever be used and since the purity of crude chemicals varies, the chief unknown quantity will be the reaction.

To determine whether or not the reaction is satisfactory, add one-half of the recommended amount of salt to the solution and take a reading for reaction, described later in the chapter. If the solution is not too acid, add another half pound. Concentrations of from one-half to one and one-half pounds per 125 gallons of water are within the favorable range. If the reaction is too acid, the amount of acid in the mix should be reduced. If it is too alkaline, acid should be added. For some waters the formula will contain as much as 40 per cent acid. This quantity, however, makes it hard to handle the mixture as a dry salt.

Until you are able to detect deficiency symptoms from the appearance of the plants and know how much growth can be obtained from a given quantity of plant food, you may find it advisable to make tests in order to find out if more chemicals are needed. It is necessary, as has been pointed out, to test only for nitrates and phosphates. If you know the plant's composition at maturity, the change in composition from seedling stage to maturity, the rate of growth, and the yield per area, you should have a good idea of how much of each element is present in the solution at any time without making a

test. It is understood, of course, that the only drain on the supply of nutrients comes from absorption by the plants.

Assume that a crop gains one pound per square foot of basin area each month. This is fresh, green material of which about one fifth is dry matter. On the average less than 1 per cent of this dry matter will be nitrogen. This means that nitrogen constitutes about .2 per cent of the green material. The nitrogen forms 8.6 per cent of the formula. Now simple arithmetic tells us that, if a basin measuring 10 by 2½ feet produces 25 pounds of green material per month, the crops will absorb about .05 pound of nitrogen and one pound of the plant food will contain .086 pound of nitrogen. Thus, an application of one pound of plant food per month to an area of 25 square feet planted to a crop like wheat, which has a very high absorptive capacity, will suffice to satisfy all plant needs. This does not hold precisely for all the stages of plant growth. At certain times the plant will absorb more than this amount of food. But it can be used as a guide until experimental data are sufficiently complete to allow further and more precise directions.

Distributing Plant Food

It is desirable to have the plant food, or salts, uniformly distributed, but an elaborate method of mixing it with the water is unnecessary. In a small basin the salts can be added all in one place; in large basins at several different points. An opening can be made in the seedbed and the salts dropped into the water, or they can be spread on top of the litter and washed down with a hose. As the chemicals will impair the germination of seeds and injure young seedlings, care must be taken in making the applications and in choosing the time for making them. Most crops are so spaced that no difficulty will be encountered in adding salts to the seedbed but those plants which are sown broadcast may be injured if chemicals are scattered over them.

The plant food may be applied just before water is added to the basin. The water can then be used as a means of distributing the nutrients. If the solution is constantly circulating

through the basins, as is the case in some commercial hydroponicums, the salts may be added at a central point from which they will be carried to the basins. Save for iron, which precipitates rapidly, all the major elements have a fairly rapid rate of diffusion. Thus, if plant food is added about every five feet, the diffusion process will make food available to the plants in between. Transpiration and the absorption of water by plants sets up a movement in the solution which also acts as a means of distributing the nutrients throughout the basin.

One pound of nutrients added to 125 gallons of water constitutes one tenth of 1 per cent of the weight of the solution. In comparison, the available plant food in soil makes up on an average somewhere between one one-hundredth and one five-thousandth of 1 per cent of its total weight. Obviously, then, because the nutrients make up a larger percentage of its total constituents, absorption of a certain amount of food by plants will produce more profound changes in the original character of the solution than of the soil.

In calculating how much of the chemical mixture to add to a solution, you must keep three quantities in mind: (1) that which produces the best growth of an individual plant; (2) that which produces the largest number of normal plants per unit area; and (3) that which requires the least labor and care. These amounts cannot be given in simple figures but must be determined from principle.

First, you must remember that a nutrient solution which is too concentrated cuts down the absorption of water by the plants, while one which is too dilute retards the intake of nutrients. Furthermore, a large volume of dilute solution may carry one plant to full size and maturity. But, if another plant were also inserted, the amount of food available would not be sufficient to support both of them. To correct this situation, you would keep the volume of the solution constant and increase its concentration.

In another case, both the volume of water and the amount of plant food in a solution might be satisfactory. But, if either one were reduced and the other kept constant, the crop would suffer.

To some crops it makes little difference whether the concentration of the solution stands at two tenths of 1 per cent or two hundredths of 1 per cent. However, the latter concentration would have to be renewed ten times as often in order to provide the same amount of food to the plants.

If you start with a concentration of 1,000 parts per million, you may allow the nutrient solution to evaporate to one-half its original volume or be diluted by rain to twice its volume without any harmful effects. So long as the minimum quantity of nitrogen and phosphorus is maintained, you need not worry about the other elements. Nor need you be concerned if twice the amount of salts prescribed are added inadvertently, unless you are using small basins, except as it might affect reaction of the solution.

Reactions

The acid and alkaline reaction of the solution affects plant growth both by influencing the availability of food elements in the liquid and by acting on living tissue. If it is too acid or too alkaline, the roots will be injured. If it is too slightly alkaline, some of the major elements will not be absorbed as readily while some of the minor ones, particularly iron and occasionally manganese, are rendered insoluble. The latter effect may occur even when the solution is neutral, or slightly acid.

The first symptoms of unfavorable reaction appear as browning of the root tips. With increased injury the roots become stubby, owing to destruction of the growing points.

The *p*H Scale

The most popular method of expressing acidity and alkalinity is as a mathematical ratio between the amounts of hydrogen ion, or acid element, and the hydroxyl ion, or alkaline element. The ratio is figured on what is known as the *p*H scale, which runs from an initial point just above 0 to 14. When the numbers of each ion are equal in the solution, the *p*H reading is 7, or neutral. This is the reading for pure water, in which

acid and alkaline ions are produced by the dissociation of water molecules.

For every ten-fold increase in the concentration of one, or the other, of the acid and alkaline elements, the *p*H reading will change one number. If the alkaline element is increased, the number will be higher; if the acid is increased, the number will be lower on the scale.

The chemicals used in nutrient solutions are salts, products of reactions between an acid and alkali. The change in reaction brought about by their addition to the liquid depends upon the quantity and the character of their constituents. The major chemicals do not contain hydrogen or hydroxyl ions but cause reaction changes by dissociating water molecules. One gram of hydrogen ions is equal in effect to seventeen grams of the hydroxyl ions. These are the amounts contained in ten million liters of pure water and give the neutral reaction, or reading of 7, on the *p*H scale. From the table of molecular weights you can weigh out the mixture which will contain 10 grams of hydrogen ions and 170 of hydroxyl ions. Either of these amounts, if added alone to pure water and completely dissociated, will change the reaction one point. But they will not have the same effect on a more concentrated solution. This is because, the more concentrated the solution, the smaller is the number of molecules in the added chemicals which will split up into ions.

Returning to the example of pure water, if enough acid is added to increase the hydrogen ion content from one to ten grams per ten million liters, the reading will change from 7 to 6 on the *p*H scale. On the other hand, if enough alkali is added to increase the hydroxyl content from 17 to 170 grams, the *p*H reading would rise to 8. Thus, as the reading proceeds from 7 downward, the solution becomes increasingly acid, and from 7 upward, increasingly alkaline.

Satisfactory Range of *p*H

The most favorable *p*H reading of the nutrient solution is from 5 to 6.5. This is for plant growth in general. For rooting

of most crops the best range is from 5 to 6. However, if conditions are favorable for good root development, crops will grow well in neutral or even slightly alkaline solutions; also some plants thrive in more acid solution than *p*H 5.

Unless the *p*H is so alkaline or acid that living tissue is affected and the root points damaged, reaction bears principally on the availability of iron. Conditions leading to unavailability of this element are treated fully in the chapter on Symptoms. It is enough to point out here that, if conditions are favorable to root growth, the plants can absorb needed iron even though the solution is slightly alkaline.

Determining the *p*H

The *p*H of the nutrient solution can be determined by the use of two chemical indicators: brom cresol green and phenol red. These are used as liquids and can be obtained from chemical supply houses. The first tells you if the solution is too acid, and the second if it is too alkaline. To take a reading, fill a glass about one-fourth full of solution. Then add one drop of brom cresol green from an eyedropper. If the indicator turns yellow or brown, the nutrient solution is too acid. If it turns dark blue, it is not too acid but may be too alkaline. Your next step is to add a drop of phenol red. If the liquid turns yellow with this indicator and blue with brom cresol green, the reaction is favorable. Charts showing the various shades of the colors mentioned will prove useful to you. After you have acquired sufficient skill, phenol red is the only indicator that will be needed, as you can gauge the reaction by the rate of change from red to yellow.

Phenol red gives a red color in neutral and alkaline solutions and yellow in acids. If a drop of phenol red is added to a solution with a *p*H of 4 or greater acidity, the change of color to yellow is so quick that it cannot be seen. At *p*H 5 to 6.8 a fringe of red is visible, when the drop first hits the solution, gradually changing to yellow. The greater the acidity, the quicker the change of color. When phenol red turns yellow,

the reaction is acid, and if the change from red to yellow can be observed, the reaction is favorable to plant growth.

Indicators are also available as impregnated slips of paper, of which a small piece is dropped into the solution. Indicators that only show whether a solution is acid or alkaline are inadequate to give all the information needed. You should know how acid or alkaline the solution actually is and at what *p*H it changes color.

Buffer Action of Carbonates

Character and quantity of the solutes in the water used will be of importance to reaction. Most of the natural waters have an alkaline reaction due to the presence of carbonates and bicarbonates. Large amounts of acid will be needed to overcome the effect of these substances, for they have what is known as "high buffer properties"; that is, high resistance to change in reaction. Thus, more acid is needed to change the *p*H when alkalinity is due to carbonates and bicarbonates than when it is caused by the presence of other salts. When dilute solutions are being used, the reaction will change more quickly with the addition of acid.

Determination and change of the reaction are often regarded as extremely difficult matters to handle. Actually, if you know how to use your indicators and add the chemicals properly, it is very simple.

Though an important feature, the nutrient solution is not the most important. Many factors remain to be considered and will be treated in the ensuing chapters. Particular attention should be paid to the sections on Aeration and Iron. Remember that natural growth requires the coördination of many factors, and that growth in hydroponics is natural growth.

CHAPTER FOUR

Water

NATURAL waters differ in their properties according to the amount and character of the substances dissolved in them. The housewife who complains because the water she uses is too "hard" actually means that it contains excessive amounts of calcium or magnesium compounds. To "soften" the water she adds other materials which alter its properties by changing its relative composition. So we see that most water exists in the form of a solution rather than as a pure compound of hydrogen and oxygen.

NATURAL WATER, A SOLUTION

In hydroponics you should know the composition of the water being used. Unless you possess this knowledge, you can hardly hope to obtain the correct chemical mixture for the nutrient solution. There is always the danger that you may add large amounts of certain substances to water already high in these same elements, with the result that their concentration in the solution reaches toxic levels. The only way to avoid making this mistake is to know what substances, and how much of each, the water contains.

It may be well to define the term *toxicity* as it is used here. Large quantities of solutes (dissolved substances) in the water may upset the life processes of the plant by physical force. This is true even when the solutes are essential nutrient elements. Small quantities exert no appreciable physical influence but

may derange plant processes by chemical reaction. Growers commonly refer to both these conditions as being toxic. In this book, however, "toxicity" is used to designate only those unfavorable effects which are brought about through chemical reaction.

Salinity

Salinity refers to and is used as a measure of the quantity of solutes contained in water. It is the term commonly applied to salts of the sea and to soluble inorganic substances contained in water from alkaline land. Less frequently it is used in connection with the solutes in ground waters from humid regions. In this book it is used to denote all soluble inorganic constituents of natural waters. For example, so-called "hardness" of water is due to salinity caused by the presence of calcium and magnesium bicarbonates. Likewise, sodium carbonate used for "softening," to overcome hardness, is a class of salinity.

Total salt content, as well as the character of the salts, affects the quality of water for hydroponic use. The physical properties of solutions vary with their saline content. This salinity is quoted either as a weight in volume measurement, that is, by grains or milligrams per gallon or liter, or by weight expressed as the number of parts of solutes per million of water. Because the physical property of the solution, when expressed as an osmotic force, cannot exceed certain limits without harming the crops, it follows that the greater the natural salinity of the water the less leeway there is for the addition of nutrients. Furthermore, the elements should be present in their proper percentage relationships, and those used in large quantities constitute a correspondingly large part of the total concentration of the nutrient solution. If elements which are not needed, or are needed in small quantities, are already present in large amounts in the water, you must add correspondingly larger amounts of those nutrients which the plants need in quantity. Thus, the original salinity of the water determines how much chemical plant food can be added before the solution becomes too concentrated. Furthermore, the character of the salinity determines in what form and how much of each nutrient must

be added to obtain the correct proportions between the elements in the solution.

The effect which the character of a water's solutes has on its salinity is well illustrated by a comparison between ground water and sea water. Ocean waters are too saline even when diluted thirty-five times; that is, to a concentration of about 1,000 parts per million, which is equal to that obtained by adding one pound of nutrient salts to 125 gallons of water. This is the recommended concentration for the hydroponic solution when pure water is used. It will not necessarily render ground waters unfit for use. The difference lies in the fact that ocean salinity is caused chiefly by sodium chloride while that of ground water is caused by mixtures of carbonates, bicarbonates, sulfates, and chlorides of calcium and sodium. Sodium chloride has a much smaller molecular weight than the salts of ground waters. Consequently, it has more molecules per a given percentage of salinity and is capable of exerting greater osmotic pressure.

Excessive Salinity

The point at which salinity becomes too high is not definitely known, but information from various hydroponicums indicates that it lies within the range from 1,500 to 2,500 parts per million. The potential osmotic pressure of solutions in this range may not be too high but the non-essential elements constitute so large a proportion of the solutes that abnormal composition of the plant may result. This would cause curtailment of plant growth. When pure water is used, plants may grow quite well in solutions of greater concentration than 2,500 parts per million. Usually, however, pure water will not be used. And experience has shown that you should be very cautious in using water containing such large quantities of solutes that addition of nutrients will bring the solution up to the 2,500 mark. The best growing conditions seem to be obtained when chemicals are added to water containing solutes so that the total concentration is between 1,000 and 1,500 parts per million.

Effect of Climate

Elements not absorbed by the plants increase in concentration as the water is used up. The time required for the solution to reach too high a concentration depends upon the original salinity of the water and the rate at which it is used. Rate of use is in turn influenced by rate of growth and character of environment. Therefore, the effect of salinity on the properties and fitness of a solution for crop production will vary with climatic conditions. A given water may give satisfactory results in one locality but not in another.

Types of Water

Classification of waters according to the properties imparted by their solutes is necessarily quite arbitrary. However, some clear idea of hydroponic technique may be obtained by arranging them in the following categories:

1. Saline waters well-suited for use.
2. High-saline waters that can never be used.
3. Low-saline waters containing toxic elements which may or may not respond to corrective treatment.

Comparatively few non-saline waters contain substances which render them permanently unfit for hydroponic use. Some may, however, require treatment before they are suitable. For example, some spring and ground waters contain harmful quantities of sulfides. These can be rendered harmless by allowing the water to stand in shallow basins with its surface exposed to air before being used. In another harmful class of substances are the borates, which render water permanently unfit for hydroponic use since there is no practicable way of removing them. Boron is needed only in very small quantities by the plant, so water containing even traces of this element must be watched carefully. Various saline waters and some mineral springs contain toxic concentrations of manganese.

Unless contaminated by industrial waste products, natural water usually does not contain toxic concentrations of salts of

the heavy metals: copper, zinc, nickel, and cobalt. There is some danger, however, that water passing through copper and zinc fittings may dissolve harmful amounts of these elements.

It is doubtful whether any ground water contains too much iron but, if so, it can be rendered harmless by aeration or by the addition of hydroxides. These chemicals precipitate the iron out of solution.

Aluminum occurs in large quantities in certain springs and in acid waters. Toxic concentrations of this substance can be treated in the same way as those of iron. Acid waters should always be examined thoroughly before any attempt is made to use them. Sulfuric acid is usually the cause of the acidity and can be corrected by the addition of lime. Occasionally, however, hydrochloric acid is the offender and any attempt to correct this condition results in the formation of chlorides even more undesirable than the sulfates.

City water supplies are usually treated with disinfectants, of which chlorine is the most common. The effect of such substances on water for hydroponic use has not been studied but it is improbable that they would prove harmful to plants.

Some materials not toxic to plants may still prove undesirable. For example, selenium in certain forms may be absorbed by the plant without harm but crops containing this element may be harmful when fed to animals. Fluorine is another element in this category. Nothing is known about its effect on humans when eaten as part of the plant. But the fact that very small amounts of it in drinking water cause discoloration of the teeth shows the need for positive knowledge as to fluorine's role in plant nutrition, for the chances are that more of this element will be contained in crops grown by hydroponics than in those produced by agriculture.

Most waters contain from 100 to 1,000 parts per million of dissolved material. The average for well-water used in hydroponicums now operating exceeds 500. This is a higher figure than that reached in most run-off and drainage water from land. At the same time these ground waters, particularly those orginating in and draining arid lands, are usually higher in solutes than are lakes and rivers. Rivers draining agricultural land

average well over 200 parts per million. But there are many mountain streams, lakes, and rivers that average considerably less than 100. A complete analysis need not be taken of water containing 100 parts per million, or less, provided it is not unfit for drinking and irrigation. When salinity exceeds 200 parts per million, have the water analyzed.

Examples of Saline Waters

Study of the following tables and the explanatory material following each of them will give you a better idea of the relative salinity of waters from various sources and the steps which are taken to render them fit for hydroponic use.

TABLE IV

Salinity of Some Fresh-water Lakes *

Lake	*Location of Test*	*Salinity (p.p.m.)*
Lake Superior	Sault Ste. Marie, Mich.	58
Lake Huron	Port Huron, Mich.	105
Moore Head Lake	Maine	14
Yellowstone Lake	Wyoming	118
Lake of Zürich	Switzerland	141

* Data from Geochemistry Bulletin 330, U.S. Geological Survey.

Lake waters of the type shown in the above table are of such character that the basic formula can be used with but slight alterations. Their chief solute is calcium bicarbonate, which requires less of the acid in the formula in order to obtain the desired reaction. The non-essential elements are not present in sufficient quantities to prevent you from obtaining a favorable salt proportion by adding nutrients until the concentration of solutes reaches one tenth of 1 per cent, or ten times the original salinity. You will probably lose a small proportion of the nutrients because you will have to change the solution before they are entirely used up. Smaller additions of chemicals can be made to waters of higher salinity and there is less loss when replacement is necessary. The greater the natural salinity of the water, the more frequent must be the changes.

TABLE V

SALINITY OF SOME RIVERS *

River	*Location of Test*	*Salinity (p.p.m.)*
Thames	West of London	270
Seine	Bercy	254
Rhine	Strassbourg	232
Danube	Regensburg	204
Nile	Khartoum	174
Hudson	New York	112
Mississippi	Minneapolis	200
Mississippi	New Orleans	166

* Data from Geochemistry Bulletin 330, U.S. Geological Survey.

As the table shows, rivers usually have a higher salinity than fresh-water lakes. They also contain more colloidal material. While some slight adjustments might be necessary, it is improbable that water containing a large amount of colloidal material will be unfit for hydroponic use. The basic formula can be used with the waters shown above. Their chief solute is calcium bicarbonate. This type of salinity provides about as much calcium as one application of the basic formula; that is, one pound of nutrients per 125 gallons of water, or a concentration of 1,000 parts per million. Thus, when the basic formula is used, the amount of calcium in the water will be doubled. This is not serious but, since plants cannot absorb the excess calcium, the solution will eventually become too concentrated and have to be changed. For this reason you will receive better results by leaving the calcium nitrate out of your formula.

TABLE VI

SALINITY OF RIVERS IN ARID REGIONS *

River	*Location of Test*	*Salinity (p.p.m.)*
Arkansas	Rockyford, Col.	2,134
Arkansas	Little Rock, Ark.	559
Brazos	Waco, Texas	1,066
Colorado	Yuma, Arizona	702
Missouri	Bismarck, N. D.	440
Kansas	Topeka, Kansas	766

* Data from Geochemistry Bulletin 330, U.S. Geological Survey.

Rivers rising in arid, or semi-arid, regions have much higher salinities than those of humid regions. This is primarily due

to a high concentration of chlorides. The waters shown in Table III can be used for hydroponics but careful adjustment of the formula is a prerequisite. Well waters from such regions may be assumed to have even higher salinities than the rivers. Because of high transpiration in these regions and the high concentration of non-essential elements in the water, the nutrient solution is apt to increase in concentration quite rapidly. For this reason you should use large basins. It is obvious that the change in concentration of a solution will be only one fourth as great in a basin twenty-four inches deep as in a basin six inches deep, other factors being equal.

TABLE VII

ANALYSES OF WATERS FROM COMMERCIAL HYDROPONICUMS IN P.P.M.

Elements	*Reported as*	*Waters*				
		A	*B*	*C*	*D*	*E*
Silicon	SiO_2	33	33	16	—	44
Iron	Fe_2O_3	4	4	trace	—	—
Aluminum	Al_2O_3	1	7	trace	—	—
Calcium	CaO	5	89	10.2	31	73
Magnesium	MgO	6	57	trace	3	76
Sodium	Na_2O	272	6	trace	144	159
Potassium	K_2O	1	—	—	—	—4
Nitrogen	NH_3	—	—	—	—	—
Sulfur	SO_4	11	35	3	35	76
Chloride	Cl	5	6	2	40	145
Phosphorus	P_2O_5	—	—	—	—	—
Bicarbonates	HCO_3	536	268	—	263	285
Total solids		639	505	181	—	660
Ignition loss		105	7	125	—	—
Inorganic matter		534	498	56	473	577

Four states—Maryland, New Jersey, Illinois, and California—are represented by the waters in the above table. Full information on the methods used by analysts is not available. Hence it is not known whether the item "Total solids" means the total in parts per million for the water. It is obvious that they were not less than the amounts shown after "Inorganic Matter" which averaged 516 for four samples. Inspection of the data, however, leads one to believe that parts per million for some of the samples were higher than indicated by "Total solids." The amount of sodium oxide and bicarbonate reported for water A

indicates that the chief solute was sodium bicarbonate and that its concentration was 736 parts per million. In water C the parts per-million of inorganic solutes is apparently less than that indicated as "Total solids" because "Ignition loss" is high. Organic and inorganic substances oxidized by heating constitute ignition loss.

Water A contained 639 parts per million of solutes and practically none of the major nutrient elements. Consequently, the problem in using this water was (1) to provide the needed elements in as small a quantity as possible so as to keep the total concentration from becoming too high; (2) to correct the high alkalinity shown by the presence of 536 parts per million of bicarbonate; and (3) to offset the high sodium content by liberal addition of calcium.

This was done by the following procedure: Before the nutrients were added, gypsum was scattered in the basins to increase the calcium content of the water. The nutrients were compounded according to the basic formula except that acid was added to correct the high alkalinity. The addition of the nutrients brought the total concentration to 1,500 parts per million.

Basins used in this case held six inches of water. Replenishment of water lost by transpiration doubled the original salinity of the water. The proportion between elements in the solution, particularly sodium and potassium, became progressively more unfavorable as transpiration increased the concentration of the former and absorption by the plants decreased that of the latter. Relatively frequent drainage and refilling of the basins with new solution were necessary.

Water B was from a limestone region. The total solids of 506 parts per million represented almost half the concentration desired in the nutrient solution when pure water is used. Although the alkalinity was high, the water did not contain large amounts of non-essential elements, and favorable salt proportions were obtained with a smaller quantity of nutrients than in the case of water having high alkalinity due to sodium salts. The problems involved in compounding a formula for this water included: (1) to provide the needed elements from

chemicals which would not increase the concentration of those already present, and (2) to correct the high alkalinity. In solving this situation potassium nitrate was the only one of the major chemical elements of the basic formula to be used. Phosphorus, supplied in acid form, aided somewhat in correcting the alkalinity. However, sulfuric acid was the major element used for this purpose. The nutrients added combined with the solutes of the water to raise the concentration of the solution to about 1,000 parts per million.

Transpiration did not cause as great an increase in salinity as in the case of water of equal osmotic pressure derived from sodium salts. However, more phosphorus was precipitated as insoluble calcium phosphate and thus rendered unavailable to the plants. No tests have yet been made in commercial hydroponicums with ammonium phosphate in water of this type. For certain crops this salt can probably be used to advantage.

Water C was relatively low in inorganic matter. Its characteristic feature was the high ignition loss for the amount of total solids. The data given were too incomplete to provide a definite explanation for this phenomenon. High ignition loss in ground water is usually due to organic matter or bicarbonates. In view of the low concentration of the bicarbonates in alkaline earths, the inference is that water C contained considerable amounts of organic matter. The effect suspended material in natural water may have on the nutrient solution is still unknown. River waters usually contain much suspended material. The same is true of waters from farm wells. There is no apparent reason why such waters should be unsuited for hydroponics. It is probable, however, that suspended organic and inorganic materials may cause a certain amount of precipitation of nutrient elements, particularly iron and phosphorus. When the effect of a certain water on the nutrient solution is unknown, you will be wise in making preliminary tests. In this particular case it was possible to use the basic formula.

Water D contained sodium salts, both chlorides and bicarbonates, in quantities that became excessive as water was used up by transpiration. The problem in this case was to (1) offset the absorption of sodium and chlorides by the plants; (2) cor-

rect the excessive salinity; and (3) keep the concentration as low as possible while still maintaining a favorable proportion of nutrient elements. As the water contained none of the major chemical foods in excess, the constituents of the basic formula were used. A concentration of about 1,500 parts per million gave good results but required relatively frequent renewals of the solution. The calcium originally contained in the water proved of advantage as a counter for the relatively high sodium content. Treble superphosphate was used as a source of phosphorus. This material, as explained in the chapter on chemicals, is composed largely of mono-calcium phosphate.

The fifth and last of our sample waters, water E, has high permanent hardness and a high total salinity. It is the most undesirable of the lot because of its large sodium chloride content. A sizable amount of acid was needed to bring the reaction within the range needed for crops. The chemical formula was designed (1) to provide the necessary elements, (2) to prevent excessive absorption of chlorides by increasing the concentration of nitrates and phosphates, and (3) to keep the total concentration as low as possible while still maintaining as favorable a proportion of the various food elements as circumstances would permit. The addition of nutrients brought the total concentration of the solution to 2,000 parts per million. Had the water been free of chlorides, a concentration of about 1,000 would have been sufficient. The increase in concentration as water transpired was more than twice that of a solution containing 1,000 parts per million with the same water loss. From this it becomes plain once more that the rapidity with which unfavorable growth conditions develop depends upon how far the proportion of nutrient salts in the solution differs from that in the plant itself.

CHAPTER FIVE

Planting

THEORETICALLY, any crop that produces roots can be grown by hydroponics. This does not mean that all of them will eventually be produced by this method. Plants differ widely in their cultural requirements and their adaptation to hydroponic conditions. The question of adaptability is chiefly one of rooting properties; for, if a plant roots well, you will have little difficulty in supplying it with the proper amounts of food.

Root development results from the interplay of three things: the plant's heritable properties, the climate, and the character of the nutrient solution. Choose plants whose heritable properties, or individual characteristics, will provide for good growth when the other factors are favorable. In other words, plants which normally have sturdy root systems are the best suited to hydroponic conditions.

A plant's suitability for soilless production can be estimated by its root-top ratio; that is, the ratio between the weight of roots and the weight of leaves and stalks it produces. There is a fairly direct relationship between the amount of water and nutrients a plant absorbs and the size of its newly formed, or feeding, root system. But, as the plant grows older, this relationship no longer holds, since a larger percentage of the root system becomes aged and inactive. Consequently, the root-top ratio of the active, absorbing roots of the plant varies with the age of the plant. It will be largest when the plant is young.

In figure 9 we see how different nutritional conditions

may influence the root development of wheat. The culture on the right received an ample supply of all nutrients; that in the center, an ample supply of all but nitrogen, which was exhausted within a week; that on the left, no nitrogen at all but an adequate amount of all the other elements. By such control of the food intake of the plant we may produce wheat

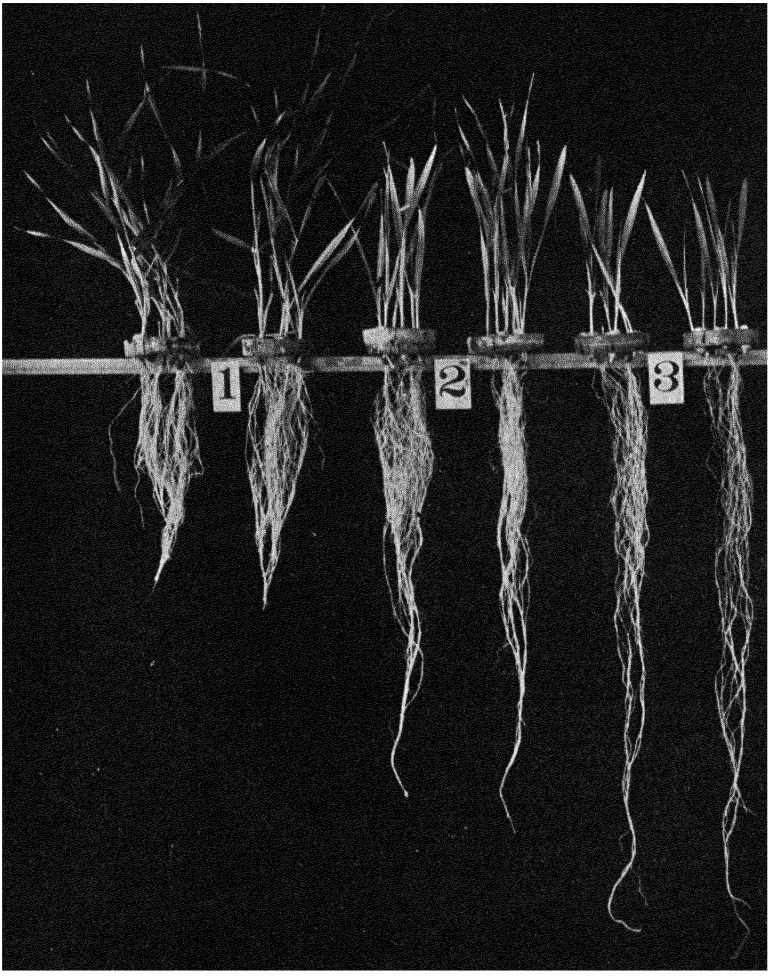

Fig. 9. Wheat plants grown under different nutritional conditions. The plants on the right received all the proper nutrients. Those in the center had all but nitrogen in ample quantities. Those on the left had no nitrogen at all.

having anywhere from 5 to 50 per cent of its total weight in roots. The best yields cannot be obtained with either of these extremes. Yet plants showing such wide adaptability to varying growth conditions are well-suited to hydroponics.

Classification of Plants

No statistical data on the root-top ratios of different plant species are available. Such information could not be gathered in soil culture. But, for the purpose of orientation, we classify plants arbitrarily into three groups: those having high, low, and medium ratios.

The high-ratio class includes those whose roots constitute from about one fourth to one half or more of their entire weight. Such delimitations are naturally only approximate. These plants are the ones whose roots become storage organs, as in the case of carrots or beets, or conducting organs for water and nutrients, as in trees and shrubs. Such roots will not develop to their natural size when immersed in liquid. For example, the carrot may start to enlarge in the solution but, unless the liquid is lowered after considerable growth, so that the feeding root alone remains submerged, the crop will not develop to the desired size.

All crops of high root-top ratio are doomed to failure in hydroponics unless cultural technique can be so devised as to differentiate the plants' feeding roots from their thick storage and conducting roots. It is relatively easy to do this with such crops as carrots, beets, and turnips; not so easy with trees and shrubs. Happily, the latter do not require such large root systems when grown in liquid as when rooted in soil. If the plant is able to produce new roots throughout its life, the alterations in root-top ratio brought about by hydroponic conditions will not prove harmful.

There is some question as to the best method of measuring root-top ratio in root crops. It may be based on the weight of the product when marketed. Thus, in the case of the carrot, it would be the ratio of the weight of the edible portion and attached roots to the green weight of the top.

Plants in the low-ratio class include those less than one eighth of whose weight is in their roots. Among them are some of the most important floral and vegetable crops—pansies, begonias, melons, and cucumbers. Many of them do well in hydroponics but are easily influenced by unfavorable conditions. A low root-top ratio means that the roots are used only for the absorption of water and food. They never develop into storage or large conducting vessels. Consequently, any impairment of their growth means a reduction in the amount of food and water made available to the plants. Naturally, such plants require more careful and specialized attention than do those of the other classes.

Plants whose roots make up from one eighth to one fourth of their weight are included in the medium class. Among them are practically all of the important field and vegetable crops grown for leaves and seed, as well as many floral crops. Under ideal hydroponic conditions their root-top ratios stay nearer to normal than do those of plants in the other two groups. It is from the species in the medium class that you should make your choice when first starting to experiment with hydroponics. Among the advantages they offer are their wide adaptation and distribution in nature, and their ability to produce new root systems each year. The ones best suited to hydroponics are those with fibrous roots which develop both downward and laterally. They provide adequate anchorage in the seedbed and an efficient absorbing mechanism in the solution.

Hints for Growers

While following the foregoing suggestions, also keep these hints in mind:

Choose annuals rather than perennials for your first experiments. The latter require a period of dormancy which makes them more difficult to handle than plants that are started fresh each year from seed or seedlings. If annuals are well taken care of during their early growth, they can often be forgotten during the rest of their cycle—at least so far as nutritional factors are concerned.

Choose crops with great ability to recuperate from unfavorable conditions. This most important qualification is reflected in the rooting properties of plants. Production of new roots is the function of youth. Plants that retain this ability throughout their lives are also able to produce new stalks and leaves continually. As long as new roots are constantly being formed and the root crown is protected from drying or drowning, part of the old root in the solution may be destroyed without permanent injury to the plant. For example, it is this ability of the tomato to produce new roots from any part of its stalk in contact with moist litter that makes it such an easy crop to grow.

Constant rejuvenation of plants can also be encouraged by judicious employment of their ability to produce tillers, or new shoots, from their buds and root crowns. In some species a tiller is essentially a new plant with its own roots more or less differentiated from those of the mother plant. Consequently, species that produce large numbers of tillers have correspondingly extensive root systems. Tillering is highly developed among members of the grass family, such as wheat and rice, also in some of the important flowers, like chrysanthemums. These crops are easily maintained in a healthful state and are well adapted to hydroponics.

Select plants that can thrive under a wide range of temperatures. There is no simple method of distinguishing by their outward appearance between plants that can and cannot do this. It is simply a matter of knowing their characteristics.

Finally, because of the great prevalence of mosaic and virus diseases in plants, be sure that your planting stock is clean and disease-free. Unless you are an expert, your best chance of obtaining desirable seed is to follow the experience of veteran growers in your own section. There is every reason to believe that disease-resistant crops eventually will be bred especially for hydroponics. But this field is still unexplored. Meanwhile, it is possible that hydroponic conditions will be particularly conducive to certain mildews, rusts and rots caused by fungi and bacteria. Therefore, choose plants which are resistant to such maladies. But bear in mind that, while you may obtain seed of plants resistant to them in soil, no one can yet

give you absolute assurance that these varieties will also be resistant when grown in nutrient solutions.

So much for the "do's." There are also some "don't's" to be kept in mind. For example, don't expect plants to grow in solutions where they have never grown in soil. Out-of-door crops cannot be grown in the house, where light and temperature conditions are markedly different. Proper illumination is a matter of distribution as well as of quantity.

Don't expect plants with high light requirements to do well when planted late in the season. Their early growth, except in species which require dormancy during that period, should take place during the months when days are growing longer. On the other hand, plants with low light requirements may be planted during the late summer and fall when the days are becoming progressively shorter.

Some Specific Crops

The field crops best adapted to outdoor experimentation by one relatively inexperienced in plant production include the small grains: spring wheat, barley, and oats. These can withstand both frost and hot weather, thrive under a wide range of light intensities, and have great recuperative powers.

Among the garden plants and flowers easiest to grow are tomatoes, potatoes, sweet corn, dahlias, marigolds, and gladioli. Within four months after planting, these crops should be ready for harvest. Tomatoes, dahlias, and marigolds will continue to fruit or flower after the first picking.

In caring for the plants named you will encounter enough different features of growth and cultural technique to gain the experience needed for more difficult procedures. Under normal conditions, two months of proper care during the early growth stage will be enough to supply all the nutrient factors necessary for production of a satisfactory harvest with some crops.

Whether or not it is economically practicable to grow a certain crop by hydroponics depends on the margin between the cost of chemicals and the average market price. To a large

extent this margin is determined by the chemical requirement of the plant. The potato, for example, is an ideal plant for hydroponic production. It has a very low chemical requirement because the tubers, which under ideal conditions constitute at maturity from 90 to 95 per cent of the weight of the plant, are composed mainly of water and starch. Corn has a fairly high chemical requirement, since the grain makes up 20 or 30 per cent of the plant at maturity. Probably this crop could be grown economically alone only during an era of good market prices. And wheat, which has a very large requirement, due to the fact that its grain is so high in mineral content and nitrogen, cannot be grown economically at present. The reason crops vary in cost of production, also lists of those that can be grown economically by hydroponics and those that cannot, are given in Chapter XVIII.

Sowing

Planting in hydroponics is essentially the same as in agriculture. Seeds sown directly in the field are also sown directly in the litter seedbed. Those transplanted in agriculture are likewise transplanted in hydroponics from soil beds, in which the seeds have germinated, to the litter seedbeds. In both types of culture a special technique is used for planting each crop. There are, however, differences in the physical method of planting and transplanting, owing to the different character and properties of the media which supply moisture, air, and heat to the plants. Soil planting has four advantages:

1. Tools and implements are available for soil planting. In hydroponics this must be done by hand.

2. More uniform moisture conditions prevail in soil, and hence seeds which are difficult to germinate start growth more easily.

3. Some seeds must be weighted down to hold the seedlings in place, for the growing roots may lift them out of a litter seedbed.

4. Better root systems can be obtained in open, well-aerated

soils, particularly sand and fine gravel, than in litter. Naturally weak-rooting crops will do better in this type of earth.

On the other hand, hydroponics is favored by these conditions:

1. Vegetable litter can be hand-planted more easily than soil.
2. Broadcast seeding, the simplest method of all, is more adapted to hydroponic conditions.
3. Species having easily germinable seeds and strong root systems establish themselves more quickly.
4. Planting of mixed species is more practical.
5. The litter is better suited to seeds that require shallow planting for aeration and must be kept cool and moist. For example, in forest nurseries where seeds are sown in a shallow layer of sand, hydroponics provides better conditions for germination than normal methods.

General Rules

There are certain general rules for planting both seeds and seedlings. The problem is to bring them into contact with water held as a film around fine particles of porous material. The water must be held tightly enough by surface attraction to prevent free movement but not so tightly that seeds and roots cannot absorb it. If these conditions are met, the air essential for germination of seeds and rooting of young plants becomes available. The season of planting must also be chosen carefully because of the varying temperature requirements of the different crops.

Some seeds such as wheat, barley, radish, beans have a great attraction for water and can sprout even though the moisture content of the seedbed is too low to support seedlings. Seedbeds might be too wet for sprouting but not after plants are up. A greater range of water content can prevail during the initial periods of absorption and germination by the seeds than later when the roots begin to develop. The character of the litter largely determines this range. Seedbeds that drain rapidly fol-

lowing saturation yet have a high capillary water-holding capacity are ideal.

Practically all seeds can stand an initial soaking. In fact, this practice is used by some growers to hasten germination. But, after a few hours of immersion, during which the seeds first start to swell, their viability will be destroyed unless they are exposed to humid air. We see, then, that planting is essentially a matter of bringing the seed, and also the new roots of transplants, into contact with capillary water and a moisture-saturated atmosphere within a certain range of temperature. This moisture-air-temperature relationship is influenced largely by the character of the seedbed material.

The nutrient solution plays no part in germination except to moisten the seedbed. Absorption of mineral food is not necessary for germination, or for the inception of new roots in the transplants, since they derive some nourishment from their seed. Nevertheless, most plants require additional nourishment from outside sources before the food content of the seed is entirely depleted. In general, seedlings from large seed do not require added nutrients as soon as those from small seed. Seedlings of the same size usually require about the same amount of food unless they are of markedly different species.

Young plants can be transplanted more easily from nutrient solutions to soil than from soil to solution. When transplanting from soil to solution, you need not retain all of the root structure, for new roots adapted to life in a solution will be formed from the root crown. The soil-grown roots will simply die if immersed in the free liquid. On the other hand, the roots of solution-started seedlings establish quick and effective contact with moisture held on the particles of soil.

Steps in Planting

In most cases you will find it more convenient to sow seed broadcast than in rows. To prevent sowing the seed too thickly, you should know about what percentage of it will germinate. If the seeds are small and difficult to scatter evenly, you can mix them with some filler, such as soil, before sowing

them. By using a large amount of filler, you will achieve a more uniform distribution.

The bed of excelsior or straw in which the seed is to be sown need not be thicker than is necessary to prevent seeds from falling through into the solution. After the sowing has been done, this layer of material should be covered with suitable litter. By moistening the litter, you will make it easier to spread and also more compact. Unless there is some special objection to it, soil should be scattered in a thin layer on top of the bed to increase its weight. About one half inch of covering is sufficient for most seed. More may be necessary for those which require some weight—such as beans, peas, daffodils—to prevent the growing roots from raising them out of the seedbed.

You may fill the basin with nutrient solution either before or after planting. You may even wait until roots have started to develop. It is well to add some nutrients to the seedbed for the benefit of crops which root laterally. For this purpose you may use one pound of the basic chemical mixture to every 25 square feet. Do not include this in your calculations when you later add nutrients to the solution, even though some of it will be washed down into the basin by rain or sprinkling.

Until seedlings have appeared, the seedbed should be kept moist by sprinkling if necessary. After the roots have started, sprinkling will no longer be necessary, since the bed will be moistened by conduction from the solution below.

Transplants may simply be set into the litter or you may have to insert their roots into the solution. This depends upon the species and will be more fully discussed for specific plants in later chapters.

Classification of Crops

Only a general classification of crops according to their distinctive planting requirements can be made. Essentially, three groups of plants can be differentiated according to planting technique: (1) those propagated from seed, bulbs, or tubers; (2) rooted seedlings both of annual and perennial plants; and (3) unrooted cuttings. Plants of the first group require fairly firm planting and often the seedbed should be weighted with

soil to hold the seed in place. Rooted seedlings require greater care in placing of the root crown so that it is protected both from drowning and drying out. Cuttings usually root better in coarse sand or gravel flats than in a litter seedbed.

Small seeds, like those of tobacco or snap-dragon, require a firm seedbed and germinate more readily in soil than in litter. Fairly large seeds that absorb water easily germinate in one about as well as in the other. Examples of these are wheat, corn, and beans. Species like lettuce, turnips, and radishes, which have small seeds and tap roots but do not require a deep seedbed, germinate readily and establish themselves quickly in litter. However, other tap-rooted species need deep seedbeds and start more easily in soil.

In sowing any crop directly into the seedbed in which it is to mature, you must consider the ability of its roots to cross the air space between seedbed and solution. Some roots have difficulty in crossing a half-inch space while others can traverse one as wide as three inches. The width of the air space through which roots are able to pass reflects to a certain degree the amount of water held as a reserve in sprouted seeds or seedlings. Obviously, a small seed cannot hold as much in reserve as a large one. Consequently, most flowers and lawn grasses cannot send their roots across as wide an air space as can the ordinary vegetables. When dealing with large seeds, remember that those which produce heavy, thick roots and can raise the seedling out of the bed if not weighted down will require a smaller air space than those whose roots are of only medium size. Peas are an example of the former and corn of the latter type.

Some of the most popular annual flowers, such as chrysanthemums and carnations, are started as green cuttings. They require a moist, open medium and usually do better in light soil or coarse sand than in litter. This is also true of hardwood cuttings like those of the rose. After they have been rooted in soil, they are transplanted to the seedbed. On the other hand, there are cuttings, including willows, gardenias, and sweet potatoes, which do not require a firm substratum for rooting. They can be started in the hydroponic seedbed.

CHAPTER SIX

Physical Conditions

EVERY land plant has a range of temperature in which it grows best. And, because plants are creatures of their environment, this range is wider for those grown in temperate or frigid zones than for those in the tropics, where temperatures are maintained at more constant levels. The limits of the range cannot be stated definitely, since they vary with different stages of growth and also with the plant part tested. For example, roots usually cannot stand as high temperatures as the leaves and stalks. But dormant roots, and in some species active roots as well, can stand lower temperatures than leaves. In general, we may say that the best growing temperatures are a little nearer the maximum than the minimum limit of the range.

Studies undertaken to find the optimum temperatures for early plant growth have illustrated the complexity of temperature effects. Data have been gathered on the effect of various maintained temperatures on the germination of seed. Germination was measured by the length of the sprouts. It was quickly found that the best temperature for germination of a species was by no means also the best for plant growth as a whole. Germination occurred within a one-phase system of environment and, so long as plant activity was confined to this system, one fixed temperature served the purpose. Once the plant had developed to the point where it existed in a two-phase system—that is, with its roots in soil and its leaves and stalk in air—a fixed temperature for all plant parts was no

longer in accordance with the natural pattern. There had to be a difference between soil and air temperatures if the best growth was to be obtained.

We now know that the rate at which certain chemical reactions take place doubles with every temperature increase of 10 degrees Centigrade. Within certain limits this is also true of various plant processes and even of growth of the entire plant. Some varieties almost double in weight when the temperature under which they are cultivated rises from 15 to 25 degrees Centigrade. But this consistent relationship between heat and growth occurs only within a very small section of the range of temperatures affecting plant activity. Because plant life is a complex of different processes, temperature increases that hasten one may retard another. Frequently, it is not the average temperature for the entire day but the range from day to night that is the determining factor. We may take potatoes and tomatoes as an example. A temperature range from 85 degrees Fahrenheit during the day to 60 at night is more beneficial to these plants than the maintained average temperature of 72.5 degrees.

Differing degrees of heat and cold are needed to foster the various processes which contribute in their turn to the development of the plant. Responses to such temperature changes are among the most apparent of plant activities but are also among the most difficult to measure in constructive and specific terms. Some plants should be allowed to develop their roots in relatively cool weather before producing stalks and leaves which require higher temperatures. For example, daffodils started at the same temperatures under which they normally bloom will be inferior to those started in cooler weather. Yet other plants can withstand higher temperatures during their early growth than they can later in life.

The length of time that a given temperature persists has a most important bearing on its effect upon plants. Plants, like other forms of life, may recuperate from shocks of short duration but, when unfavorable conditions are maintained, permanent injury often results. Those temperatures near the

maximum cannot be resisted for as long a time without injury as can those near the minimum.

Temperature Balances

In growing any crop by hydroponics you should strive to provide it with the same natural temperature pattern existing in regions where the highest yields are obtained in soil. So you must strike the best possible balance between temperatures required for the different plant processes. The cereal grains, for example, sprout most quickly at temperatures ranging from 28 to 31 degrees Centigrade. However, wheat and barley maintained at these high temperatures lack sturdiness. This quality is measured between the girth of the stalk and its length. The highest ratio—in other words, the thickest, sturdiest stalks —is obtained at the lowest growth temperature, but best yield of grain is obtained with stalks of moderate girth-length ratio.

To use another example, the rate at which grain ripens (or, for that matter, the rate at which any maturation process proceeds) should be balanced against the rate of growth required to produce the highest yield. The growth cycle ending in the production of viable seed may be cut to one-third of normal or even less by a marked increase (or, in other cases, a decrease) in temperature. Wheat that normally requires 120 days of growth can produce ripe grain within 40 days after planting if exposed to high temperatures. In the first case the yield of well-filled heads may be as high as fifty bushels or more to the acre. In the latter the heads will contain a small number of shriveled kernels.

For still another illustration of the complexity of temperature effects we have only to consider the relationship between root and stalk growth. The temperature which at first brings about rapid stalk growth does not produce a correspondingly rapid growth of roots. Eventually, if the proper balance between these two features of growth is not restored, the plant's life will be shortened and its yield impaired. This is particularly true of cool weather crops, such as potatoes, the root vege-

tables, and flowers propagated from bulbs. These plants are not adapted to forcing by heating the nutrient solution as can be done with tomatoes.

The amount of roots required to support a given amount of leaves and stalks varies between species. The relationship between these plant parts—often expressed as the root-top ratio —is an indication of temperature effects as well as those of other factors. And the influence of temperature varies with other factors much more than any of them vary with each other.

Temperature and Plant Growth Phases

While it is impossible to determine precisely when a given temperature is too high or too low, you should be familiar with reactions occurring at different temperatures and phases of growth.

The early life of the plant is devoted particularly to root development. There are always exceptions to any general rule, but we may designate the important small-grains cereals (wheat, rye, and barley), the root crops (turnips, carrots, and potatoes), and also flowers like sweet peas and daffodils as cool-weather crops having relatively high root-top ratios. Warm-weather crops having a smaller ratio of roots to tops are corn, all the vines, melons, squash, cucumbers, and tomatoes. Too high temperatures during early growth harm the first class much more than too low temperatures do the latter. Low temperatures simply check the vegetative growth of warm-weather crops and, consequently, the root-top ratio is not adversely affected.

Pollination is another vital process affected by temperature changes. As a rule, the flowers which contain the pollen of the plant cannot stand as wide a range of temperatures as can the leaves. In most agricultural crops fertilization will not occur at temperatures which permit leaf growth. Consequently, the crop may fail not because temperature is unfavorable to all growth but because it inhibited one particular plant process. For this reason some crops benefit greatly when the temperatures are controlled at the time of pollination.

Classification of Plants

There is no set method by which you can determine beforehand a plant's resistance to injury by temperature fluctuations on the basis of its physical appearance. Therefore, until you are able almost instinctively to analyze your cultural technique in respect to temperature control by its effect on plant conformation, an arbitrary classification of plants as to their tolerance of heat or cold may prove helpful.

Among the garden crops, corn, beans, tomatoes, peppers, egg plant, melons, squash, and cucumbers should be planted when the solution temperature is around 70 degrees Fahrenheit. In many regions the solution will go to 80 degrees or higher with very good effect on the plants. When air temperatures range from 70 to 95 degrees, the solution temperature will fluctuate between 65 and 80. The lower limits of this range may be too cold for some of the plants mentioned but, if the season is long and the upper limits are also attained, all of them can be grown successfully. If they are produced under glass in regions of ample sunshine, the solution temperature can be held around 75 or 80 degrees. The limits of the ranges mentioned will depend upon the amount of seedbed litter used and upon the temperature of the water. An occasional air temperature of 100 degrees or more will not harm the plants. But, should such hot days be successive, you will have to take measures to ameliorate their effect.

High temperatures of around 100 degrees are more harmful to floral crops grown under glass than to those grown outside. When grown out of doors, garden flowers such as zinnias, dahlias, marigolds, asters, and cannas will grow under these temperatures.

Cool weather vegetables, like potatoes, onions, beets, peas, chard, and spinach, should be planted early in the spring when solution temperatures run from 55 to 65 degrees Fahrenheit. Gladioli, pansies, daisies, fibrous rooted begonias, and snapdragons may be planted at the same time. Daffodils and tulips, which are propagated from bulbs, should be planted even earlier.

If the season of favorable temperatures is short and it becomes necessary to carry the crops into an unfavorable season, planting should be timed so as to allow the crucial period of plant development to come during the favorable season. In floral crops this crucial period comes during flowering (or pollination) and in other crops during fruiting.

Heating the Solution

Unfortunately, some people have been led to believe that the nutrient solution must be heated. There are no experimental data to support this view. Heating is necessary only if the solution is too cold, and other conditions favorable.

But it cannot make up for such requirements as good light or adequate food. The proper temperature for the solution is determined by the interplay of all plant-growth factors, and heating without regard to these brings no special benefits in its wake.

Nevertheless, hydroponics offers a new field to artificial means of controlling air and solution temperatures. For crops grown in season the seedbed will offer the most important means of control. But for out-of-season production, shelter and artificial temperature controls will be needed. At present three general methods of fixing solution temperatures for off-season production are used. The first consists of the conventional practice of growing plants in a heated greenhouse. This method is used for plants which require fairly uniform day and night temperatures. It probably will have wider application in regions of cold winters than of warm and in small greenhouses rather than in large ones.

The second method involves the use of electric cables and was first used in 1934 to grow tomatoes. The surprisingly large production obtained with this method is shown in figure 17.

Sixty feet of lead-covered cable of the same type used for heating soil were laid in metal basins with areas of twenty-five square feet. The cables were coated with asphalt to prevent the lead from dissolving into the solution. Later this was found to be unnecessary although lead cable laid on fresh

cement basins deteriorated within a few months. The experiment proved quite satisfactory. However, use of electricity to heat solutions in large-scale production is costly. It is probably better suited for use in small household containers.

In the third type of operation the solution is passed through a boiler, where it is heated to the desired temperature, and then circulated through the basins. The basins themselves serve as conduits and the moving solution is the conveyor of heat. The solution enters the basin through a pipe at one end and is drained out through another leading to a sump, from which the liquid is pumped back to the boiler. Nutrients are added at the sump, but in some cases additional quantities of iron are added directly to the basins. One commercial establishment has used this system of circulating heated solutions for the past five years. Its operators have experienced no trouble with scaling of the boiler or corrosion of the pipes.

The circulatory system offers the most economical method of heating solutions for large plants. Fuel consumption and cost of equipment are markedly lower than in greenhouses heated by steam or hot water. Should it prove impractical to circulate the solution in very large basins, steam or hot water pipes may be laid in or under them. This method has not yet been tested but there seem to be no obstacles in the path of its adoption.

In hydroponicums where the solution is heated but air temperature is not, and drops low at night, moisture condenses on the leaves of plants and keeps them wet. In itself this is not serious but, if the days are cloudy and dull so that the excess moisture does not evaporate, disease may attack the plants. Also, the condensed moisture may interfere with pollination. Thus, heating of the solution may require the adoption of other control measures.

Light

Every cell in the plant leaf is a miniature chemical laboratory where carbon dioxide from the air combines with water, in the presence of chlorophyll, to produce such organic substances as starch, sugar, and fats. These are the so-called high-energy

products. The process by which they are formed is known as *photosynthesis* and the power required to produce this reaction is derived from the rays of the sun. Plants have the ability to absorb and harness this radiant energy. But, while it is their servant, it is also their master, for without the products of photosynthesis they cannot live.

It has been suggested that artificial illumination might take the place of direct sunlight as an aid to plant growth. Certain plants have been grown normally from seedling stage to maturity entirely under this type of light. Nevertheless, it is not a satisfactory substitute for sunlight in production of plants containing large amounts of the high-energy products. These plants have high light requirements which can be filled only by direct sunlight. Even those which do not need direct light must still be so placed that the rays of the sun bear on them from several different directions. The role of artificial illumination in crop production will probably be limited in the future to supplementation of inadequate supplies of direct sunlight.

The role of sunlight in plant growth can be divided into a primary and a secondary function. The first is to bring about photosynthesis. The second is to aid in such processes as pollination, opening of flowers and buds, and elongation of the stems. The light need not be intense to perform this secondary function. Artificial illumination might be used to supplement sunlight, particularly with plants having low light requirements, such as onions, peas, lettuce, carnations, chrysanthemums, and gardenias. However, we can conclusively rule out any possibility of using artificial light to produce high-energy plants. This has always been, and probably always will be, the exclusive function of the sun.

Light and Temperature

Natural temperatures are largely the result of sunlight, or lack of it, and the two are interrelated in their effect on plant growth. This effect may be of great importance in crop production. The temperature of any body is influenced by the

amount of light it reflects or absorbs. Low light intensity is frequently associated with low temperature. When light is poor, the maximum temperature which plants can stand is lower than when light is good. However, a deficiency in light cannot be overcome by an increase in temperature. And plants with high light requirements stand hot weather much more easily than those with low.

In hydroponics the range of temperature caused by varying light intensity is wider than in agriculture. This is because the materials, such as sawdust, excelsior, and straw, used in the seedbed reflect changes in light conditions more quickly than does the soil. In some cases this may prove fortunate, for certain crops grow more vigorously and produce higher yields when their roots and tops grow in markedly different temperatures. The difference between the two readings is known as the root-top temperature gradient. Where sunlight is good, a sharper gradient can be obtained with consequent better growth than when light is poor. This point is discussed more fully in the chapter on tomatoes.

Regions of Light Distribution

Because hydroponics has eliminated soil, the basis to agricultural production, it has been erroneously stated that now, at last, plants can be grown anywhere. Actually, if light conditions in a certain region are such that plants cannot grow there in soil, they cannot grow there by hydroponics. From the grower's standpoint there is absolutely no difference between the light requirement of a plant whether it is grown in soil or solution. There is, however, a great difference in the amount of light that can be used. In agriculture only a small part of the light falling on a given area is used by plants for photosynthesis. Most of it falls between the plants and is absorbed in the soil. In hydroponics, plants can be grown much closer together and thus more of the sun's rays are intercepted and used. The lone exception to this rule is when light conditions are poor. Without developing the point needlessly, we may

say that under such conditions hydroponics might give a poorer yield than agriculture.

When regions are classified according to light and temperature conditions, they naturally fall into four categories: those (1) where light is good but temperatures unfavorable; (2) where both temperature and light are good; (3) where temperature is favorable but light poor; and (4) where neither is favorable.

By "good" light is meant a supply so large that more is available than can be used, so that it becomes necessary to protect shade-loving plants from the full force of the sun's rays.

"Unfavorable" temperatures are those which prove either too high or too low. They can be counteracted more easily in hydroponics than in agriculture. Where weather is cold, it is easier to heat the nutrient solution than the soil, and in regions where weather is hot the water in the solution keeps vegetation cooler than does the earth.

Where light is poor but temperature favorable, you should grow crops having low light requirements. If you use any which have a high requirement, you will be forced to use a cultural technique to slow down their growth. This point is covered more specifically in chapters on the various crops.

Where both light and temperature are either favorable or unfavorable, distinctive relations between the two are not involved and thus need cause you no concern.

Symptoms of Light Deficiency Injury

Symptoms of light insufficiency vary with the type of foliage. Thin-leaved, rapidly growing plants quickly deplete the small reserve of chlorophyll stored in their tissue. When light conditions are such that more cannot be manufactured, the leaves of such plants turn lighter in color. On the other hand, thick-leaved, slow-growing plants whose leaf surface does not increase so rapidly can make their stores of chlorophyll last longer. Thus, their foliage will not show the symptoms so quickly. The color designating good growth is a medium shade between the darkest and lightest hues of green. Trained observers can recognize deviations from this color within a few days after light

becomes poor. But to do this you must know your plants intimately.

Inadequate light may also be reflected in an increase of foliage at the expense of fruit. This has been particularly noticeable in several hydroponicums where tomatoes were grown in winter. The solution was heated and consequently the root temperature was high. The plants grew very fast. Leaves and flowers were large but fruit was sparse and often deformed. The last effect was due to lack of light for pollination. Artificial illumination offered no relief. Additions of carbon dioxide to the air did give encouraging results but data on this point are still too incomplete to allow conclusions to be drawn.

There is a theory that setting of fruit is affected by the ratio of carbon to nitrogen in the plant's composition. Carbon is necessary for the production of starch, sugar, and cellulose. It is taken from the carbon dioxide in the air and fixed in the plants through the process of photosynthesis. Thus, to build up large amounts of the food products mentioned, direct sunlight is needed. When light becomes poor, less carbon is fixed by the plants and its ratio to nitrogen, whose intake by the plants is less affected by light conditions, becomes narrower. It has been found that, when the light supply is low, better growth can be obtained by lowering the nitrogen intake of the plants. Lowering the temperature of the solution to slow up the growth is also advantageous.

When intense sunlight falls upon a surface of high reflecting power, temperature great enough to injure the root crowns and tops of the plants may arise. Injury from this source is not detectable at the time. It is reflected later in such factors as hastened maturity and poorer quality of the product. Bulbs, tubers, and perennials may not show injury until the following season. Your best protection against such an occurrence is to take temperature readings at the surface of the seedbed on hot days. From this you can gain an idea of the reflecting power of the litter and change it if necessary.

Inadequate light cannot cause injury by reflection. Instead it lowers the air temperature until it is so close to that of the

solution that the root-top temperature gradient is poor. The solution temperature is fairly constant so long as the liquid is covered. Consequently, air temperature should not be allowed to drop below certain levels. This does not mean, of course, that air temperature determines the rate of growth. As we know, root temperature is an important contributing factor in this respect. It is thus possible for a given root temperature to be ideal in summer when light is good and too high in winter when light is poor.

Situating the Basins

The city dweller who wishes to use hydroponics in his home garden will usually encounter more diverse light conditions than the farmer. In the city, trees and surrounding buildings may shade the basins. On bright summer days the sunlight may produce higher temperatures because the neighbors' houses cut off the prevailing winds. Surrounding objects reflect more light and heat in the city than in the country. Furthermore, the materials used for seedbed litter are lighter in color than soil and will reflect heat more readily. Consequently, if you are planning to use hydroponics in a home garden in a city residential district, you must plan the location of your basins and choose your crops as carefully as if you were installing a commercial hydroponicum.

At night the leaves of plants turn in toward the stem. In some species this turning is very pronounced. In others it is hardly noticeable. Nevertheless, it is a part of the natural scheme of plant life. When light strikes the leaves again in the morning, they turn outward. This response to a stimulus is called "tropism." Should an object, such as a tree, cast a shadow over the hydroponicum at three o'clock in the afternoon, when normally this shadow would not gather until the setting of the sun at seven o'clock, the plants will turn their leaves inward some hours earlier than nature requires. The possibility of such an effect being produced by shading must be considered when the position for the basins is chosen.

Light Requirements for Various Species

Crops may be classified arbitrarily into groups having high, low, and medium light requirements. Among the common vegetable, field, and floral crops, those that are thin-leaved, grow rapidly, and show iron deficiencies quickly belong to the first category. They include corn, potatoes, tomatoes, dahlias, marigolds, and sunflowers. Many of the intensely colored flowers that die within a day or so after blooming belong to this group. They should be fully exposed to the light throughout the day. Satisfactory yields of potatoes, tomatoes, peas, beans, all the root crops, and many of the flowers can be obtained with eight hours of continuous sunlight through the morning and midday. Crops having high starch, protein, and sugar content will require longer periods of direct illumination.

In the low light class are those plants which grow slowly, have thick leaves, low iron requirements, and sparse root systems. Examples are begonias, carnations, gloxinias, and pansies, all plants of intense coloring that bloom for long periods of time.

Crops with fairly thick leaves, large root systems, and a moderate growth rate, such as cabbage, cauliflower, beets, spinach, sweet peas, daffodils, and tulips, belong in the medium class.

Remember that the demarcations between the classes mentioned are not precise but are offered to aid you in the absence of more exact data. Some of the crops placed in the high light-requirement group can be grown successfully under the same conditions as those in the medium group. The main purpose of drawing up such an arbitrary classification is to impress upon you the fact that the light requirements of different plants vary and that you must choose them to fit the surroundings and light conditions in the place where your hydroponicum is to be situated.

Air

Except for a class of bacteria known as anaerobes, neither plants nor animals can exist without air, great life-giving substance from which they take oxygen and to which they return

carbon dioxide. This process is called respiration. But plants, unlike animals, use air as a raw material from which to manufacture their own tissue. Animals use it more as a protection for structure already existing within the body. Plants use carbon dioxide as well as oxygen, while animals absorb only the latter.

Land animals, surrounded entirely by air, live in a one-phase system. Land plants exist in a two-phase system composed of free air and soil or, as in the case of aquatic plants, free air and water. In aquatic plants there is a sharp boundary between the two phases. Not so in the case of plants living in soil. Their leaves and stems are encompassed by air; their roots by water held as a thin film on the particles of porous earth. But between these two sections of the plant is another part—the root crown—which exists not in air or water alone but in an atmosphere saturated with moisture.

As was pointed out in the chapter on seedbeds, the different environmental conditions under which these sections of the plant live in soil must be duplicated in hydroponics. Thus the plant is held so that its leaves and stem are in air, its root crown in a moisture-saturated atmosphere, and its feeding roots in a solution which is itself saturated with oxygen. The leaves and stems will naturally receive sufficient air under these circumstances. So your problem becomes one of providing oxygen to the solution, from which it can be absorbed by the feeding roots, and to the seedbed, from which it is absorbed by the root crown.

If oxygen is denied any part of the plant, disintegration will set in. This may start as a break-down of the tissue or result from the action of anaerobic organisms, which thrive in the absence of air. Strangely enough, these organisms cannot develop without oxygen but obtain their supply by feeding on the plant tissue which contains the life-giving element.

Animals succumb quickly once they are denied oxygen but plants do not. Consequently, plants can be resuscitated just as a partially asphyxiated human being can be saved by prompt administration of oxygen. At the same time, however, this ability of the plant to stave off death makes it harder to recog-

nize symptoms which herald the beginning of its suffering from lack of air.

Aeration in Hydroponics and Agriculture

You may think it strange that plants will die when soil is too wet but will thrive in nutrient solutions. Actually, the two situations are not comparable. When there is too much water in the soil, the plant's root crown is submerged and cut off from its air supply. A similar situation arises in hydroponics only when plants are immersed above their root crowns in the solution. So long as the seedbed is of proper composition and structure and an air space is maintained between it and the solution, this cannot occur.

An analogy may be drawn here between cultivation of the soil in agriculture and preparation of the seedbed in hydroponics. The farmer tills the earth to make it porous so that air will readily filter down to the roots of his crops. He avoids working the soil when it is very wet, for this might reduce its porosity, and he adds organic material to lighten the earth. Aeration in agriculture is based upon arrangement of fine soil particles into aggregates that will allow the entrance of air into its upper layers. Likewise, in hydroponics, aeration of the root crown depends upon building the seedbed in such a way that it, too, allows air to penetrate the litter.

Bubbling Air Through Solutions

Scientists growing plants in bottles have found that growth can be improved by bubbling air through the solution. This is true simply because the land plants are being grown in the same way that aquatic plants grow in nature. Since the bottles are kept filled, there is no zone of moisture-saturated air around the root crown. Also, the air removes waste products that naturally form when the root systems are entirely submerged. This is not the way in which plants are grown in hydroponics. Thus, when proper conditions are provided, bubbling air through the solution is unnecessary.

It may even be harmful, for it produces longer roots which may be advantageous in agriculture but may not be desired in hydroponics. New roots should have their nutrient-absorbing parts as close to the leaves and stem of the plant as possible. It is in this position that they do their best work.

Differences in Roots of Corn and Sunflower

Unless new roots continue to arise from the root crown, a progressively larger air space will be needed to care for the old roots. The old roots become adapted to living in air saturated with moisture rather than in the solution. If, after becoming so adapted, they are again immersed in the solution, they will disintegrate.

Observation of this in nature during my boyhood in Nebraska furnished the clue to aeration technique. A neighbor's corn field in the tasseling stage was badly infested with sunflowers. From the road the field appeared a solid mass of yellow. A heavy rain falling steadily for several days submerged the field, thus immersing the root crowns of all the plants. Within a short time the sunflowers began to wilt and finally died. The corn was not damaged. In later years, while experimenting with the growth of corn and sunflowers in nutrient solutions, I allowed the liquid to recede until it filled only the bottom third of the jars. After the plants had grown under these conditions for a short time, the jars were again filled with solution. The sunflower soon began to droop and then died. The corn was unaffected. This aroused my memory and soon the answer became plain. The sunflower is a shallow, fine-rooted crop which draws its moisture mostly from the top layers of the soil. These layers are drier than those below. Consequently, the roots of sunflowers became adapted to living in a dry soil containing a large amount of air. They acquired many of the tissue characteristics of old roots and those parts of the plant which normally exist in air. When submerged in water they drown, for the oxygen dissolved in the liquid cannot supply their needs. The corn roots, on the other hand, are not affected. Corn is a crop with appreciably thicker roots

which drive deep into the lower and wetter portions of the root zone.

New and Old Roots

Newly formed roots require but little oxygen and take what they need from the water. The best way of providing the necessary amount is to keep the solution as shallow as possible, or practicable, and at the same time expose a large portion of its surface to air.

The older roots are provided with air by filtration through the porous seedbed. While these roots have usually lost their ability to absorb nutrients, they must receive enough air to keep them intact for the life of the plant.

You see then that aeration in hydroponics must be considered in terms of the air requirements of young and old roots. Both require different conditions. You must strike the most favorable compromise possible between the two.

Classifications

It is impossible to make a hard and fast classification of plants according to their rooting properties. However, the following arbitrary arrangement of plants into certain classes may point the way to development of proper aeration technique.

As long as roots are growing and forming new tissue at their ends, they will not disintegrate. So the first classification is made on the basis of the length of time that different plants will produce new roots. Some, like tomatoes, perennial grasses, and ferns, grow new roots during their entire life span. Others, and these include most of the strictly annual plants, produce new roots only during the early part of their growth. And there are still others that make roots even after their leaves have fallen off. You will obviously want to start the plants under the best of conditions. Thus, as long as they are forming new roots, you need not change your method of aeration. But there will come a time when new roots will no longer be produced and after that more air must be provided to prevent the root system from disintegrating. Bubbling air through the solution

is one way of providing an increased supply but it is far simpler to lower the water level in the basin and thus provide more air space. This air, saturated with moisture, will provide conditions similar to those in nature.

The second classification orders plants on the basis of the depth to which they penetrate. It includes those having shallow roots with many laterals and those with deep, thick roots from which finer ones strike out in all directions. The sunflower is an example of the first type while corn illustrates the latter. When grown in solution, the roots of these two plants appear quite similar. Their properties are not altered, however, and they respond differently to aeration. Size of the root crown is the main important difference between them so far as hydroponic technique is concerned. This is the portion of the plant which requires a moisture-saturated atmosphere. It will drown if completely submerged and dry out if the air around it is not filled with water. In shallow-rooted crops, such as sunflowers, it is smaller than in deep-rooted ones such as corn. It follows then that the deep-rooted crops can thrive under a much wider range of conditions and do not require such careful tending. A large root crown may be partially submerged and still have enough of its tissue exposed to air to enable continued growth. Or the top part of it may be dry and still the lower levels will absorb enough moisture to fill its needs. Consequently, the level of the solution may be allowed to fluctuate rather widely without adversely affecting a deep-rooted crop. This is not true of the shallow-rooted crops with their smaller root crowns. A comparatively slight change in depth of the solution may submerge their root crowns or leave them exposed to drying air.

Another comparison may be based on the protein content of plants. Plants high in protein, such as beans, peas, and alfalfa, require more ideal conditions and will not grow as well when poorly aerated as will low-protein crops like sugar cane, rice, and corn. There are two possible reasons for this: more oxygen may be needed to manufacture the products of high protein plants or else they give off larger quantities of harmful waste material which must be removed from the solution by aeration.

As examples of high protein crops the legumes might be offered. They are extremely sensitive to an excess of water in the seedbed. Nodules will not form on that part of their roots which is submerged in the solution but appear in very large numbers on that part which is in the seedbed or in the moisture-saturated air space.

The relative vigor of root growth offers us a fourth basis for comparison. Plants having vigorous roots can grow under a greater range of conditions than those having weak roots. The development of adverse growing conditions for the plant of vigorous roots is recognized more easily than in the case of plants with weak roots. Consequently, you may find it profitable to use vigorous plants in your first experiments when you are just beginning to grasp the principles of aeration. Nevertheless, there is something to be said for both types in hydroponics. Vigorous plants require more frequent adjustment of aeration conditions. Some of the weaker ones, while they are more susceptible to changes in growth factors, are easier to grow once the exact conditions required have been established.

Influence of Climate on Aeration

Methods of aeration vary according to the climatic conditions under which plants are grown. For example, dissolved oxygen is needed in the solution. The oxygen content of water is highest at a temperature of 68 degrees Fahrenheit. When temperature rises above or below this point, the amount of dissolved oxygen in the solution begins to decrease. Consequently, more air must be provided in hot climates than in cooler ones where water will not be absorbed so quickly and where, because of the slower growth of the plants, their need for air will be smaller.

Weather conditions also play a large part in determining how much water the plants will use. Temperature and prevailing winds influence transpiration, which in turn is tied up with the water requirement. The greater the amount of water used the larger becomes the amount of air supplied to the roots of the

plants. This air-water relationship must be adjusted from time to time by replenishing the water supply in the basin.

You will find it wiser to allow the solution to drop for a rather long period of time and then add comparatively large quantities of water than to make frequent additions and thus maintain the solution at a constant level. The latter course is contrary to the plan of nature. Under natural conditions, rains wet the soil to its field capacity. Then the plants absorb water from the earth and let in more air. Later more rain falls and the water content of the soil again rises. This process continues throughout the growth period of the plant. You will reproduce it most exactly by making less frequent but larger additions of water to the solution.

Those unfamiliar with the principles of aeration have expressed concern over the effect of excess rain on crops grown in open-air basins. Their main concern is with the possibility that rain will dilute the solution. This is really only a minor consideration. The real danger is that rainfall will saturate the seedbed and submerge the root crowns of the plants. The remedy for this lies in the use of litter which has a low water-holding capacity and in setting the overflow pipes in the basin at a low level. Rain is often valuable as a means of aeration, for it supplies dissolved oxygen to the solution.

Symptoms of Poor Aeration

Aeration must be considered in terms of each nutrient element in the solution, for all of these affect root growth. After seedlings have produced roots and begun to absorb nutrients, the nutritional factors begin to have a bearing on aeration. Too high a concentration or an unfavorable proportion of nutrients in the solution, an excessive amount of non-essential elements, or an unfavorable chemical reaction with the liquid: all these are factors which affect root growth and thus present aeration problems.

The first symptoms of poor aeration vary with different crops. Those appearing during the early growth stage are slowing down of the normal rate of growth and a change in the lustre

of the leaves. The foliage assumes a peculiar color—that of age imposed prematurely upon youth. It is indescribable in any common terms but is easily detected by the expert grower. When poor aeration occurs in the latter growth stage, the change in hue is not so marked but you will be able to recognize it if you have trained yourself to diagnose plant illnesses from changes in appearance of the vegetation. The changes in color are accompanied by alterations in the texture of the leaves. These can be detected by some growers simply by feeling them with the fingers.

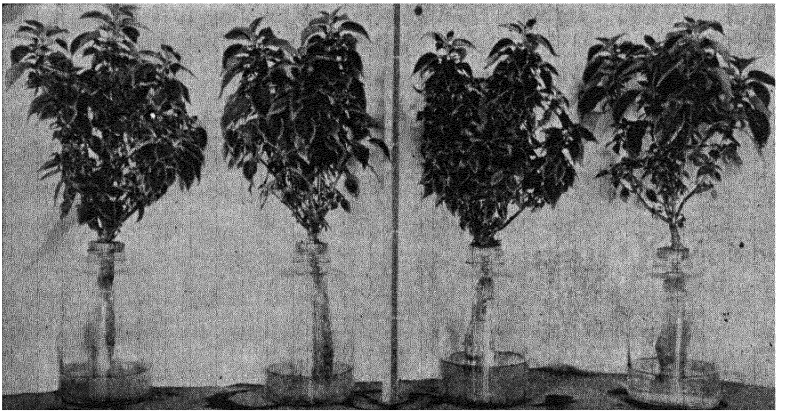

Fig. 10. The level at which the solution is maintained after the plants have obtained full size. Complete filling of the jar with solution after the roots have become adapted to moist air will kill them.

Poor aeration during the early stages of growth may starve the plants, for unless they are provided with air they cannot produce the new roots needed to absorb nutrients from the solution. Iron, for example, can be absorbed only by new roots. The symptoms of starvation due to lack of air and new root growth differ with different crops but can be recognized through the distinctive changes in color of the foliage. Whenever growth slows down in the presence of an ample food supply, proper reaction and concentration of the solution, poor aeration is usually at the bottom of the difficulty.

Some of the points considered in this and other chapters may

be cleared up easily by considering figure 10, which shows coleus growing in nutrient solutions. The cuttings were rooted in sand and, after developing roots several inches long, were placed in the glass jars shown. Whenever the liquid dropped an inch or two in the bottles, it was replenished with water. This procedure was followed until the plants achieved the size at which they are pictured. By allowing the water to recede just far enough to provide a moisture-saturated air space, it was possible to keep the roots from becoming too dry and at the same time allow proper aeration.

The illustration also bears on the problem of basin depth discussed in the preceding chapter. The distance to which water may be allowed to recede without injuring the plants provides a clue to methods of controlling the air-moisture-temperature relationship in the plant root zone—the particular province of aeration.

Aeration is not so much a matter of handling hydroponic equipment as of studying plants in nature and then devising simple methods of duplicating natural conditions. Unfortunately, no practical tests have yet been devised for determining the exact status of aeration at any particular time. Therefore, you must master the principles and processes of aeration in hydroponics just as the farmer does in agriculture. That is, by personal observation and exercise of clear judgment. By studying crops growing in the field we get the general story. But, since root systems growing in solutions differ from those in soil, you must adjust the moisture-air-temperature relationship in accordance with the properties of the medium which causes that difference. In other words, you must coördinate the physical properties of water, air, and seedbed litter in such a way that conditions prevailing in soil where crops do well are reproduced in the hydroponicum.

CHAPTER SEVEN

Symptoms of Change

EITHER a lack or an excess of essential food elements will produce characteristic changes in plants. Each change is accompanied by the appearance of certain symptoms. These, however, are not always easy to recognize. They are not uniform, varying with the growth stage and with the growth rate, which in turn is influenced by climate. Often it is difficult even for experts to diagnose the various symptoms produced under the influences of so many different modifying factors. Nevertheless, they offer invaluable aid to the grower as harbingers of more serious difficulties to come. By studying the symptoms he may be warned in time to avert serious damage to his crop.

Deficiency symptoms are studied in the laboratory by methods which exaggerate them, thus making them easier to recognize. Such procedures throw the symptoms out of their proper relationship with other factors. But at the same time they have provided theoretical knowledge on the cause and development of symptoms which has proved to be of vital importance. It should form the basis of your approach to the practical problem in hydroponics.

The symptoms produced by lack of essential elements show up in various ways, such as off-color and off-type of the plant or plant parts, insufficient growth and yield, or, in some cases, poor quality of the crop. Such symptoms are of two classes: (1) those caused by a deficiency of elements without which the plants die prematurely, and (2) those produced by a deficiency

of elements without which the plants live their normal life-span but never achieve normal size. The elements concerned in the first class include all the minor elements and some of the major ones; those in the second, only some of the major. If you include an adequate amount of each minor element in the nutrient solution at the beginning, you should have no trouble from lack of them. They show deficiency symptoms only if left out completely.

You should have a general idea of the character of each deficiency symptom and the differences in its appearance at various growth stages. Also, you should be able to recognize alterations in appearance of the plant resulting from absorption of an excess of any certain element. It is important, therefore, that you familiarize yourself with the normal conformation of the plant parts. This is a question of symmetry, the arrangement of all parts into one living whole, and cannot be defined by simple measurement. To master it you must study plants closely, so that any slight change in the proportions of a plant part may be recognized immediately either as a natural development or as the result of some upset in normal growth.

Nitrogen

Nitrogen is usually absorbed in greater amounts than any other element. Lack of it from the beginning causes diminutive plants with comparatively larger root systems, smaller and lighter colored leaves, and drier leaf tips than the normal plant. It does not in general interfere with the processes essential for growth in plants like wheat, whose seed contains enough nitrogen to produce another seed in a small plant. When nitrogen is deficient, growth proceeds normally but on a diminutive scale. But plants with small seed, like lettuce, cannot reproduce unless they are provided with this element.

Many species can reproduce from the original fund of nitrogen contained in their seed or seedlings without additional supplies from outside sources. Seed from such plants will germinate but cannot itself produce viable seed. Many cereal grains are in this class. They show increases in growth directly pro-

portional to additions of nitrogen to the solution until an excess of nitrogen becomes available. Then the ratio is no longer consistent. The excess produces very lush vegetation with a corresponding decrease in the firmness of stems and leaves. Foliage is produced rapidly at the expense of root growth, the ratio of fruit or seed to vegetation is subnormal, and the conformation of plant parts is off-type.

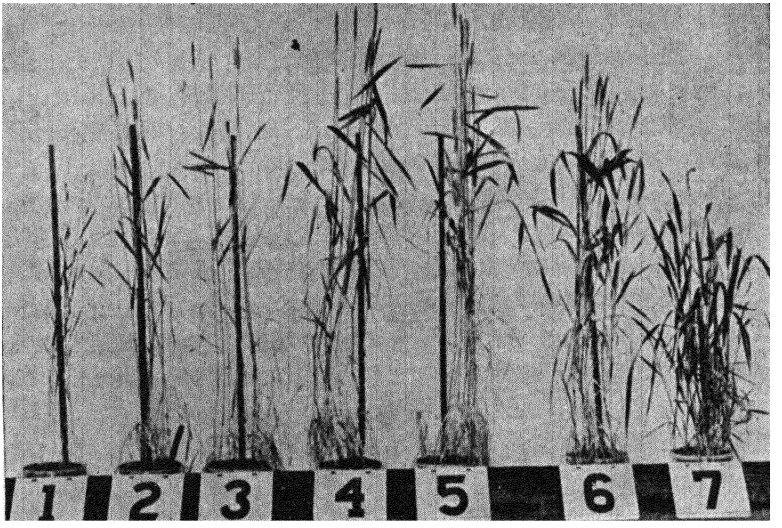

Fig. 11. Insufficient and excess plant food both curtail yield of wheat. Growth increase is proportional to the amount of nitrogen supplied up to a given point; then further additions are no longer so efficient.

In an experiment with wheat reacting to lack and excess of nitrogen, the ratio of grain to total weight of plant when nitrogen was deficient was 15 per cent (1, 2, 3). When the element was in excess, the same ratio was 20 per cent (6, 7). In a culture from which nitrogen was removed when the plants were three months old, the ratio was 30 per cent (4, 5). When nitrogen was lacking, the plants did not produce enough foliage and were unable to manufacture the starch needed for the kernels. When an excess of the element was present, too much foliage was produced; that is, vegetative growth continued too

long. This also cut down the production of grain. Starch for the kernels is not produced from new leaves but only from those which have attained some size. If a high production of grain is to be obtained, it is necessary for the plants to stop forming new leaves after they have attained size. Thus, by prolonging vegetative growth the nitrogen excess inhibits the formation of the kernels.

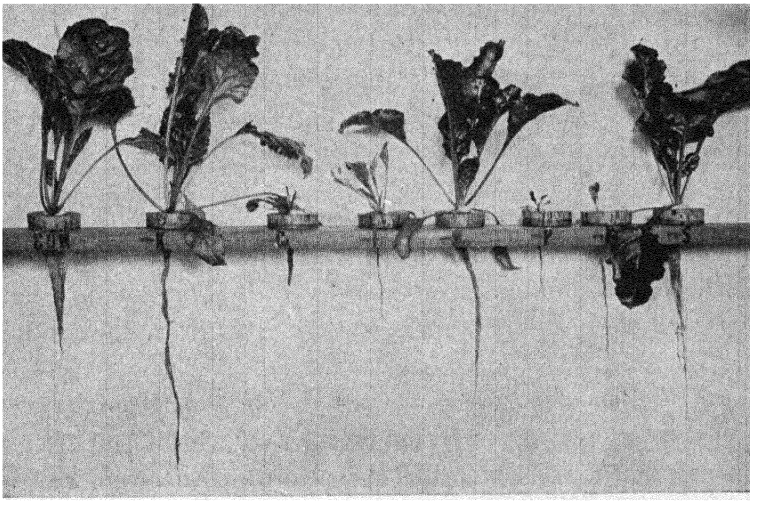

Fig. 12. Deficiency symptoms in sugar beets. The culture in (1) contained all elements. The others lacked (2) potassium, (3) calcium, (4) iron, (5) magnesium, (6) phosphorus, (7) nitrogen, (8) sulfur.

This tendency of nitrogen to cut down the storage of starch and sugar is not so important for some flowers and crops grown chiefly for their leafy tissue. However, they may also absorb an excess.

Potassium

Lack of potassium produces a greater range of symptoms among different species than does lack of nitrogen. Plants like the cereal grains, which produce central stalks or shoots, die prematurely unless provided with this element from the very beginning. In crops such as lettuce, beets, and carrots, however, the effects of potassium deficiency are less severe, and are

quickly remedied by addition of small amounts of the element to the nutrient solution.

Unlike nitrogen, potassium does not enter into fixed chemical compounds inside the plant. However, crops like potatoes, which are predominantly starch, absorb large amounts of it and produce better-quality crops if an ample supply is available. It is assumed that the element plays an important role in photosynthesis of crops rich in starch and sugar.

The deficiency symptoms of potassium can be described as a premature breakdown of the younger foliage. The leaves droop and, as deficiency continues, may change in color (becoming either lighter or darker according to species) and die. The first symptoms to be noticed are brown spots on the older portion of the leaves.

An excess of potassium makes straw and leaves of plants stiffer than normal. Sometimes the tips of the youngest leaves wilt and those of the older leaves turn brown. There is no characteristic off-color of the foliage unless growth is slowed down markedly.

Very few species can reproduce themselves from the small amount of potassium contained in their seed. The tuber crops, such as potato, are a notable exception. They contain fairly large amounts of this element, can make considerable growth from that contained in the tuber, and reproduce small tubers without additional supplies from outside sources.

Phosphorus

Lack of phosphorus also causes diminutive plants. The symptoms in young plants are a dark green to purplish color of the leaves, abnormal stiffness of stalks and leaves, poor root development, and some discoloration. The roots are longer than usual but produce few laterals.

Plants absorb an excess of phosphorus under special conditions, such as when nitrogen is lacking in the nutrient solution. It is difficult to tell the symptoms of phosphorus excess from those of nitrogen deficiency. In such a case plants are charac-

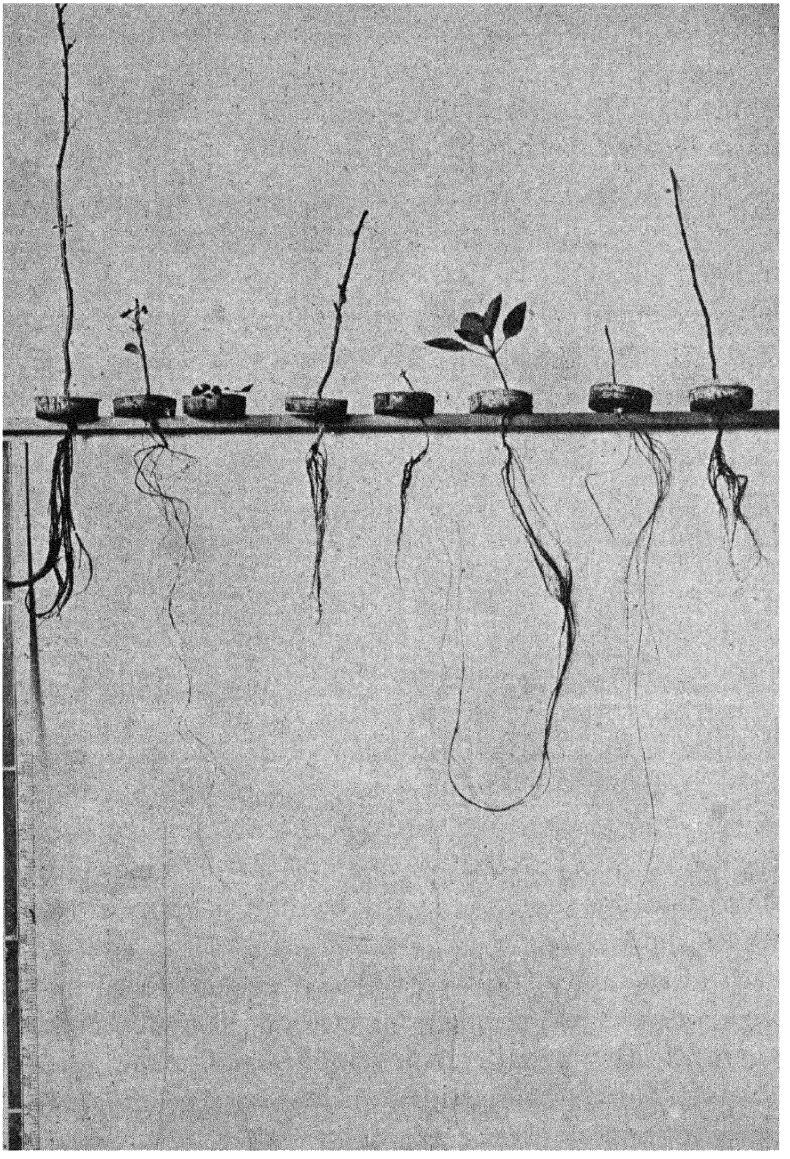

Fig. 13. Deficiency symptoms in apple seedlings. Culture (1) was complete. The others lacked (2) potassium, (3) calcium, (4) iron, (5) magnesium, (6) phosphorus, (7) nitrogen, (8) sulfur. Note differences in effects of treatments (2) and (5) on beets and on apples.

terized by large root systems, sparse foliage, stiff leaves and stems.

Species having sizable seed, such as many cereals, can reproduce without receiving phosphorus from outside sources, that contained in the seed being enough to produce diminutive plants. However, plants like lettuce, radish, and turnip, which have small seed, must be provided with an additional supply of this element to reproduce.

Calcium

Symptoms of calcium deficiency are more pronounced and appear earlier in most plants than do those of other elements. Unlike the other nutrients whose deficiency symptoms first become clearly defined on stalks and leaves, the first signs of calcium deficiency are mirrored in lack of root growth. The small roots growing from the seed disintegrate. The seedling makes a tuft of leaves which at first appear greener than normal. Eventually, they lose their color and the plant dies prematurely. Small additions of calcium to the nutrient solution have marked corrective effects.

Because lack of calcium curtails root development, a higher ratio of leaves and stalk to total weight of plant is obtained. It is with lack of calcium and nitrogen that the greatest extremes in the ratio of roots to tops are obtained. The former produces the least and the latter the largest amount of roots in relation to leaves and stalks.

Lack of calcium does not have such a pronounced harmful effect upon rice as it does on other crops. Rice requires little calcium for growth and contains only a small amount of it at maturity. The element seems to play some special part in the synthesis of proteins, for crops high in proteins are also high in calcium.

Absorption of excess calcium is possible under unfavorable cultural conditions. When these happen, the plants usually find it hard to avail themselves of iron but absorb nitrogen in larger quantities than are needed. For this reason a calcium excess

may be found associated with conditions which cause the foliage to be either a lighter or a darker green than is normal.

No species have yet been found which can reproduce from the amount of calcium contained in their seed alone, though there is a possibility that certain species of rice might.

Fig. 14. Deficiency of certain elements in the nutrient solution affects species differently. From left to right the treatments in sets of two are: (1) rice, 3 months in complete nutrient solution; (2) rice, first 1 month in complete nutrient solution, then transferred to a solution containing all essential elements except calcium; (3) cotton, 3 months in complete nutrient solution; (4) cotton, 1 month in complete nutrient solution, then transferred to solution containing all elements except calcium. Note that cotton died but rice thrived.

Magnesium

In most plants, lack of magnesium does not show up until considerable growth has been made. So much of this element is contained in the seeds that the seedlings are independent of outside supplies for quite a long period of time. Some crops can reproduce from the original magnesium content of their seed if the seedlings are not allowed to make too much vegetative growth. The chief deficiency symptom of this element is found in a high ratio of roots to leaves and stalks. The root system is of more than normal size.

A moderate excess of magnesium produces foliage a little greener and larger than is normal. When the excess becomes great, however, the leaves become smaller than average, though they retain their green color. The tips of the leaves may wilt and die if they are exposed to hot weather.

Figures 12 and 13 show that the effect of the absence of magnesium is different on beets and apples.

Sulfur

Sulfur does not fluctuate as much as other elements, hence is not absorbed in excess. A deficiency of this element does not evidence itself as early as do others. Deficiency shows late in the growth period when the plants fail to develop to normal size. Many species of annual plants can reproduce from the amount contained in their seed.

The Trace Elements

Lack of any of the trace elements is hard to diagnose from the symptoms produced when plants are grown in large basins. The stoppage of growth resulting from absence of these substances must be distinguished from a similar stoppage caused by other factors, such as improper aeration. It is imperative, then, that you make a careful investigation before adding any of these elements to the solution, for in doing so you may raise their concentrations to toxic levels.

Lack of manganese shows itself in light blotches on the older leaves, darkening of the root tips, stoppage of growth, and curtailment of the absorption of other elements, chiefly iron.

Boron deficiency likewise stops growth of the plants. Tips of the roots turn brown, the leaves take abnormal shapes, and the plant loses its lustre. The last effect is due to the stoppage of growth rather than to any specific property of the boron.

Zinc and copper do not have as striking deficiency symptoms as do the other trace elements. Smaller amounts of them are needed to keep the plants healthy. This fact has only made it

more difficult to devise a technique for studies which might reveal the symptoms associated with lack of these two elements.

Iron

Iron is unique among plant food elements in that it is the only one which ordinarily cannot be included in the original solution in the amount needed to carry crops to maturity. Although required for the manufacture of chlorophyll, the green pigment without which plants cannot grow, iron is toxic if maintained in too high concentrations. What the toxic point might be is not known, but it is safe to keep iron at not more than one-half part per million. Consequently, it must be added to the solution frequently and in small amounts so that its concentration is not excessive but still sufficient to allow constant manufacture of chlorophyll. In some cases the total amount of iron used may rank with that of the major elements, but at any particular time it will be but a minor constituent of the the solution.

Toxic concentrations of iron injure plants by reacting with the protoplasm in their roots. This substance coagulates and is then unable to perform its normal functions. The first symptoms of this type of injury appear as browning of the tips of the new roots. Pronounced toxicity may even cause a breakdown of the entire root system.

Iron Requirements of Plants

The rate at which chlorophyll is produced in the plant depends upon the amount of light available. Thus, the iron requirement also varies with light conditions. If a large amount of light is supplied to the leaf surfaces, more chlorophyll will be synthesized and used and more iron will be needed. In this respect it does not differ from the other elements, for the larger and faster a plant grows the more food it needs. But iron does differ from the major elements in that a reserve can be built up neither in the plant nor in the solution for fear of a toxic

reaction. And it differs from the other minor elements in that it is required continuously for a longer period of time.

Annual plants need iron as long as they are gaining in weight. In perennials it should be available as long as the plants have leaves. If it is removed prematurely from the nutrient solution, the new growth of the perennials after dormancy will be off-color. This is because iron is needed to make chlorophyll in the miniature leaves of the new buds.

In general, we may say that thick-leaved plants, like cabbage, need less iron than the thin-leaved ones, like lettuce. Those, like begonias, with a very acid sap need less than those, like dahlias, which have less acidity. Rapidly growing plants, like sunflowers, need more than slow-growing ones, like rhododendrons. Those with low light requirements, like ferns, need less than those, like the rose, which need much light. Thick-rooted plants, like callas, need less than the fine-rooted crops, like pansies. It is probable that low iron requirements are not due to smaller amounts of this element being needed for the amount of chorophyll produced, but that differences in absorptive power and leaf structure make for more efficient use of the supply available.

Iron Deficiency Symptoms

Under ideal conditions certain crops may be grown without any additions of iron over and above the amount included in the formula. Usually, however, iron is the first element to show deficiency symptoms. Because of the iron-chlorophyll relationship these symptoms are quite characteristic, appearing as bleaching of the leaves and stems. They show up in various forms, since all the plant features bearing on quantity, stability, and distribution of the pigment affect them. These features, and thus the symptoms as well, naturally vary from crop to crop. Therefore, you may have difficulty in diagnosing the signs of iron deficiency unless you understand the conditions under which they develop.

Symptoms may show up in rapidly growing vegetation within a day after iron becomes deficient. In plants such as young tomatoes they appear in the growing point, a bundle of minia-

ture leaves and stems which enlarge and move outward, before they become evident in the older vegetation. This holds, however, only so long as growth is rapid. If it has slowed up, they appear first as light blotches on the older leaves. In crops such as corn they develop in the same way but are quite different in appearance. The difference is due to natural variations in leaf structure. Tomato leaves have cross-veins which make for sharper demarcation of the colored spots. Corn leaves have long veins which allow the bleaching to spread more uniformly over the entire surface. Thus, the question of whether symptoms will appear first in the growing point or in the older tissue depends upon the age of the plant, its rate of growth, and the structure of its leaves.

Remedial measures should be taken as soon as deficiency symptoms become evident. Vegetation that shows symptoms quickly is also capable of swift recovery. If iron is added within a few days after the first evidence of deficiency, leaf color will be completely restored. But this is impossible if you allow the leaves to become extremely bleached. The bleaching is a sign that chlorophyll is lacking. Without this substance the plants cannot manufacture the energy foods required for root development. If this situation persists, other deficiencies will also develop and a definite derangement of plant structure will result. Of all the elements, only calcium can compare with iron in the harmful effect produced by its absence during the early growth of most crops.

Unavailable Iron

You should take care that iron added to the solution becomes available to the plants. There are various ways in which it may be rendered inavailable both in the solution and inside the plant itself.

Iron reacts readily with other elements to form insoluble salts which plants cannot absorb. Phosphates, carbonates, and hydroxyl ions are the substances with which these reactions take place in the solution. Inside the plant the reaction is usually with phosphates. It is possible for certain plants to

suffer from iron deficiency even though chemical analysis shows large quantities of this element present in their tissue. The explanation is that the iron has reacted with other elements and has become insoluble even in the naturally acid plant sap.

Iron can be absorbed only by new roots. Consequently, you must provide the most favorable conditions possible for root growth. Constant formation of new roots is the best insurance against iron deficiency.

Fig. 15. Shows the effect of light on the availability of iron to wheat. Left, wheat exposed to bright sunlight. Right, diffused light. The iron content was equal in both treatments.

Since iron is soluble in acid, the nutrient solution preferably should be slightly acid in reaction. This will forestall to some extent the formation of insoluble iron salts. On the other hand, great care must be taken to see that the solution does not become too acid. The margin between that acidity which harms plant roots and that which keeps iron in solution is very small. When we increase the acidity of a solution, we usually increase the solubility of the iron salts being used. Thus, there is danger that with increased solubility the concentration of iron in the solution will become toxic.

Other factors which render iron unavailable are (1) too

much sunlight, (2) growing algae, and (3) high temperatures. Very bright sunlight causes iron in solution to precipitate. Algae growing in nutrient solutions compete with the plants for the iron available. Under normal hydroponic conditions the seedbed will prevent light from striking the solution and also keep algae from growing in it.

The action of sunlight is illustrated in figure 15, showing wheat seedlings which were exposed to different conditions of sunlight. Those on the right were exposed to the direct rays of the sun and became bleached. Those on the left, sheltered from the sunlight, remained normal in color.

To summarize, then, you should succeed in keeping the iron in the solution available to the plants if you keep the temperature of the liquid as low as is compatible with good growth, the light exposure as low as possible without interfering with photosynthesis, and the acidity of the solution as high as possible without harming the plant roots.

Response to Additions of Iron

Plants that make new roots readily respond more quickly to corrective additions of iron than do those whose root development is slow. This is because new roots can absorb iron while older ones cannot. In general, fine-, shallow-rooted crops, like wheat, form new roots more readily than do thick-, deep-rooted plants, like corn. The fine-rooted plants have more compact root systems, and their roots are closer to the leaves. This feature aids them in making quick and efficient use of the added iron.

Sources of Iron

Iron should be added as a liquid in the form of a suitably concentrated stock solution. Any soluble iron salt can be used. Table VIII gives the solubility of common iron substances.

The inorganic salts, iron sulfate and iron chloride, are satisfactory and less expensive than the organic salts, such as iron citrate, acetate, and tartrate. The sulfate is probably more practical than the chloride, as it does not attract water so re-

ily. However, if exposed to air, it will change into a less soluble form. There is no real objection to any iron salt but you must know how much of it is present in your stock solution. The concentration of the solution is not based entirely upon the amount of iron added, since some of it will precipitate when it comes in contact with other elements.

TABLE VIII

SOLUBILITY OF CHEMICALS IN 100 PARTS OF WATER

Compound	*Cold Water*	*Hot Water*
Iron sulfate .. ... . ferrous, $FeSo_4 \cdot 7H_2O$	32.8	196.0
Iron sulfate .... ferric, anhydrous, $Fe_2(SO_4)_3$	slightly soluble	decomposes
Iron sulfate . . . . . ferric $Fe_2(SO_4)_3 \cdot 9H_2O$	very soluble	decomposes
Iron chloride		
ferrous, $FeCl_2$.. . . .	64.4	105.7
ferrous, $FeCl_2 \cdot 4H_2O$	160.1	415.5
Iron chloride		
ferric, $FeCl_3$	74.4	536.0
ferric, $FeCl_3 \cdot 6H_2O$	246.0	very soluble
Iron phosphate		
ferrous, $Fe_3(PO_4)_2$	insoluble	slightly soluble
ferric, $FePO_4$	insoluble	insoluble

Stock solutions may be made with any of the soluble iron salts given in Table VIII. For example, one ounce of one of them added to a quart of water will give approximately a 3 per cent solution. When added to 1,000 pounds of water, the amount contained in a basin 25 square feet in area and eight inches deep, this solution will produce a concentration of two parts per million of the iron salt, about one-third of which is pure iron, depending on the salt used. Addition of stock solution at this rate every week will provide the necessary iron under most conditions. Unless a very acid solution is required for the crop being grown, it should not produce an excessive concentration.

To facilitate distribution of the iron throughout the basin,

dilute the dose from ten to fifteen times and pour it on the seedbed litter in several places. The points of addition should be two or three feet apart. Pouring it on the litter is the simplest way of adding iron. But, in doing this, you will encounter another factor. The litter will fix some of the iron into an insoluble form; so, to offset this loss you increase the dose. After you become expert at handling iron, you may be able to supply the needed amount during cool weather simply by placing a few nails or scraps of iron in the basin, if the proper acidity is maintained in the solution.

The availability of iron to plants bears a relation to the reaction of the nutrient solution. It is desirable that this be maintained somewhere with a *p*H of from 5 to 6.5. However, the reaction is not so important as generally assumed from laboratory studies. More important is the maintenance of the proper air-moisture-temperature conditions of the crop's environment, because of their bearing on root growth. If plants produce new roots continually, iron will be absorbed even from nutrient solutions with a *p*H above 7.0 for many crops but not for all. The absorption of iron by plants in hydroponic culture can proceed similarly as with vegetation in soil where the reaction is alkaline. New roots in the seedbed have sufficient absorptive capacity to supply plants with iron if it is there.

CHAPTER EIGHT

Tomatoes and Other Vine Crops

In the preceding chapters we have discussed hydroponic equipment and principles of plant physiology. Now, for the first time, we consider the problems involved in growing specific plants. In the laboratory, the plant is subjected to a regimented technique, but in hydroponics the technique must be fitted to the plant. The conclusions reached in laboratory experimentation must be discarded if they fail to fulfill the requirements of practical production. We are guided first of all by "ecology," that branch of science dealing with the adaptation of living things to their natural environment.

The tomato is well suited to hydroponics and is one of the crops you may well use in acquainting yourself with the method. It grows rapidly, has marked recuperative powers, and is quite responsive to changes in cultural technique.

Classified as a warm-weather crop, the tomato requires plentiful sunshine, warm days, and cool nights. High temperatures during the night increase the plants' rate of respiration and convert the products of photosynthesis back into their elemental carbon dioxide and water. For strong, sturdy growth the plants must have cool nights during which they can turn these materials into stable products. Growers consider that tomatoes exposed to excessively high night temperatures, and which elongate too rapidly, lack substance. This means that too large a percentage of photosynthetic products is lost during the night

and that, although they gain in length, the plants make this gain without a corresponding increase in weight.

The tomato is essentially a perennial plant in frost-free regions, but is cropped as if it were an annual. Harvesting consists of a series of successive pickings. To obtain high tonnage yields you must keep the plants vigorous for a longer time than is necessary for such crops as corn and potatoes, whose entire harvest is gathered at one time.

Experimental Results

A series of experiments conducted at Berkeley, California, in 1934 served to illustrate the foregoing statements. On Decem-

Fig. 16. Tomato plants two months after being set into a litter seedbed composed of one inch of wood excelsior and two inches of pine sawdust. The basins are 10 feet long by 2½ feet wide. Each contains twenty plants. Growth was at the rate of one and one-half feet per month.

ber 19 of that year four basins 10 feet long, 2½ feet wide, and eight inches deep were planted with two-inch seedlings. Each basin contained twenty plants. They were to be studied as a "forcing crop," and by use of electric cables the nutrient solutions at the beginning of the experiment were maintained two at 70 and two 80 degrees Fahrenheit. One month later these temperatures were increased to 75 and 85 degrees and held at these figures for the remainder of the year-long test.

The varieties used were Sutton's Best and Sutton's Majestic. The climate in Berkeley is not particularly favorable for production of tomatoes out of doors, but is ideal for production under glass. Consequently, the greenhouse was not heated and its air temperatures were subject to outside influences. The variation in air temperature was in fact intensified, for the sun's radiation on the glass raised it above that outside during a considerable part of the day. When night fell, it dropped to within two or three degrees of the outside temperature. The average difference from day to night was about 35 degrees and the maximum 50. Thus, the air temperature was higher than that of the nutrient solution during the greater part of the daylight hours but lower at night.

A complete reversal in root-top temperature gradient was produced every twenty-four hours. This arose from the fact that the temperature of the solution in which the roots grew was much more constant than that of the air in which the tops existed. The gradient, a natural phenomenon in all plants, was greatest during the early stages of growth in the winter months. The air temperature ranged from about 80 to 90 degrees for the warmest part of the day down to 45 or 50 for the coolest part of the night. During the summer months the range was from 85 to 95 during the day down to 60 or 70 at night.

From the very start the plants were remarkably sturdy. Sturdiness is measured as the ratio between the diameter and length of the growing parts. It cannot be determined easily because the shoots may still grow longer after they have stopped increasing in girth. Evidence that sturdiness and general vigor of the tomato is affected by the root-top temperature gradient was

Fig. 17. The same plants shown in figure 16 four months after planting. Each has five to seven clusters of fruit and one or two clusters of blossoms. The lower clusters are about nine inches apart and average one cluster every twelve days with the temperature of the nutrient solution maintained at 85°F. The difference in the air temperature of day and night averaged 35°F. When the difference between day and night temperature was less, the clusters appeared one in nine to ten days, and were about a foot apart. Too rapid growth is not so favorable for high yield and good quality of fruit.

observed in an interesting phenomenon. After the temperature of the solution was raised, a very perceptible increase occurred in the diameter of the newer portions of the plant over that of the older ones. Since there was no increase in air temperatures, this was obviously due to higher solution temperatures causing an increase in the differential between root-top temperatures at night. Had the increase produced only a more rapid elongation of the shoots, this would have proved the temperature to be too high for maximum fruit production. The gain in girth and sturdiness was greater for Sutton's Majestic at 85 degrees and for Sutton's Best at 75 degrees, solution temperature. This indicates that the former is better suited to warm climates.

The largest yield was 352 pounds from Sutton's Majestic grown at 85 degrees. The basin area was 25 square feet, which probably makes this a record yield for so small an area. The average yield per plant in the highest-yielding basin was 17.6 pounds, the highest was 27.4, and the average per plant for all basins was 16.2. The main stalk of Sutton's Best grew from one and three-quarters to two feet longer every month during the first part of the season. Two months were required to form five clusters of fruit, nine inches apart. With the advance of the season, as nights became warmer and root-top temperature gradient less pronounced, the plants began to grow faster. The distance between clusters became greater and they formed more frequently. The result was smaller fruit. It became evident then that too-rapid growth curtails yields.

Tomatoes will produce fruit continuously for a year or more. Under ideal conditions about four months are required from the time of seeding before the first fruit ripen. In the experiments the most productive age of the tomato was found to be seven months. The monthly average over six-month and twelve-month periods was about equal. This is explained by the fact that the first pickings made during the youth of the plant are the largest.

The four basins with a walk-way between them occupied 130 square feet of greenhouse floor. The area per plant was 1.7 square feet. This spacing has since been used in some com-

mercial plants and is probably justified where good light prevails. It was too close in others.

Instructions for Growing Tomatoes

In growing tomatoes by hydroponics you will probably start with seedlings. You may start these in soil flats and transplant them directly to the seedbed with soil attached. Or you may order them from a commercial nursery, in which case the soil will be removed before they are shipped.

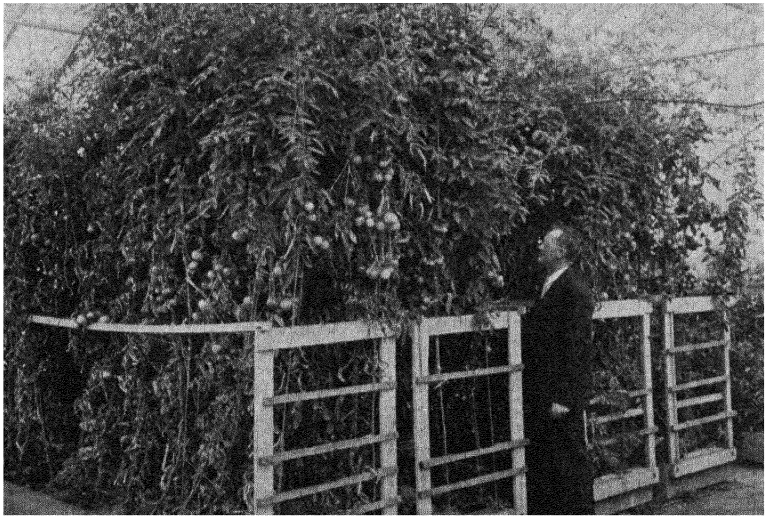

Fig. 18. The four basins covered 130 square feet. Six months after planting, the stage shown in the picture, 606 pounds of fruit had been harvested. The plants were allowed to grow one year and produced 1,224 pounds of fruit.

When using seedlings with soil attached, prepare a seedbed composed of about one inch of loose excelsior or two to three inches of straw. Seedlings in a good state of growth can simply be placed on the excelsior. You need not place their roots in the nutrient solution. New roots will form in the seedbed and penetrate downward into the liquid. After the plants have been set on the first matting, put more litter, such as sawdust,

shavings, or even soil, around them to hold them in a somewhat erect position.

Should you already have a deep seedbed, then make a hole in it for each plant. Set it in and then press litter around it.

Now, if you are using seedlings with bare roots, you must add fine material to the excelsior and straw in order to give the seedbed greater water-holding capacity. Most of the fibrous roots on these seedlings are stripped when the plants are removed from the ground. Those still attached either are dead or will die when the seedlings are planted.

In planting seedlings of this kind, dig a small cavity in the seedbed, place the plant in it, and then press litter around the stems. The plants should be brought as close to the solution as possible without immersing the root crowns. If they are long and spindly and their stems hard, plant them horizontally, so that much of the older part of the stem is under the litter. For example, if the seedlings are a foot long, cover half the stem with litter. When this is done, the new roots will form near the surface and the plant will be much sturdier, for stems that are hardened and woody will not enlarge after the plants are established. Thus, old seedlings will never develop into good plants unless the aged, hard tissue is removed. This can be done by making it part of the root system.

The procedures described may be used for transplanting seedlings started in nutrient solution. However, their roots should be placed in the solution on transplanting.

Finally, if you so desire, you may sow seed directly into the litter. This may be done in either of two ways. You may sow the seed in a small area and transplant the seedlings to the desired positions after they have reached the proper size. Or you may space the seed according to the distances at which the plants will ultimately set, thus dispensing with further transplanting. In doing this, take a pinch of seeds in your finger tips and place it about one-half inch deep in the litter. After the plants appear, thin them down until only one remains growing from the place where each pinch of seed was placed. This practice is now used in several commercial hydroponicums.

A wide variety of materials may be used in constructing the

seedbed. The crop may be grown in narrow basins, though wide ones are preferable. The basin should be filled with water to within one inch of the seedbed. The chemicals should then be added at a rate of one pound of basic formula to every 125 gallons of water, or one ounce to every cubic foot.

Fig. 19. The same as in 18 but a closer view, showing clusters between the fourth and sixth foot levels. Plants are ten feet tall with tomatoes and blossoms continuing to form.

Under ideal conditions, tomatoes establish feeding roots in the solution within two or three days after planting. Usually, however, this process requires from a week to ten days. If the plants are not in prime vigor, add plant food to the seedbed at the rate of one-fourth ounce of the basic chemical mixture to each vine. The chemicals should be placed around the plant but kept at a distance of from three to four inches from its stem. These additional nutrients will aid development of roots in the seedbed. Nevertheless, do not exceed the amount recommended; for, if too much food is added at the start, the tomatoes make too many roots in the seedbed and they may not establish a satisfactory root system in the solution. It is true that tomatoes can be grown to fair size with root in the seedbed alone, but the best results are obtained when the major portion of the absorbing mechanism is in the solution. The

main advantage of having roots in the litter is to provide anchorage for the plant and to facilitate aeration.

The easiest way of adding necessary iron is to make a stock solution and pour it on the seedbed. With a bed 25 square feet in area the solution would be added at three or four different places. There is less danger of raising the iron concentration of the solution to harmful levels when the element is added in this way than when it is poured directly into the basin, because part of the iron is fixed by the litter while it is trickling down through the seedbed.

Whether or not additions of iron will be necessary depends upon the variety grown, the climate, and the character of the water used. Increases in temperature make additions necessary by stimulating growth and decreasing the amount of available iron in the solution. Unless the water used is very pure and the concentration of plant food in the solution low, one pint of a one per cent pure iron solution is not too much to add each week to a basin 25 square feet in area and eight inches deep. The resulting concentration of iron in the basin will be about one part per million. If maintained over a long period of time, this would harm the plants. The only conditions under which this can happen, however, arise when the solution is so acid that plants cannot live in it. Because of the remarkable recuperative powers of the tomato, its root tips may be destroyed by the action of excess iron without permanent injury to the plants. Such an occurrence would kill crops like corn, carrots, or cereal grains. The reaction of iron with the proteinaceous root tips of the tomato so lowers the concentration of the element in the solution that the new root growth is not impaired.

From the available data it is impossible to determine how much ripe fruit the tomato produces from a given quantity of nutrients absorbed during early growth. Consequently, the question of just how much plant food should be added from time to time must remain unanswered. The problem is one of determining the relationship between foliage and fruit production. Some growers prune the side branches and part of the leaves of tomatoes to hasten either setting or ripening of

the fruit. However, the present lack of knowledge concerning the quantitative relationship between fruit and foliage growth prohibits the formulation of a general rule of procedure for use in tomato culture.

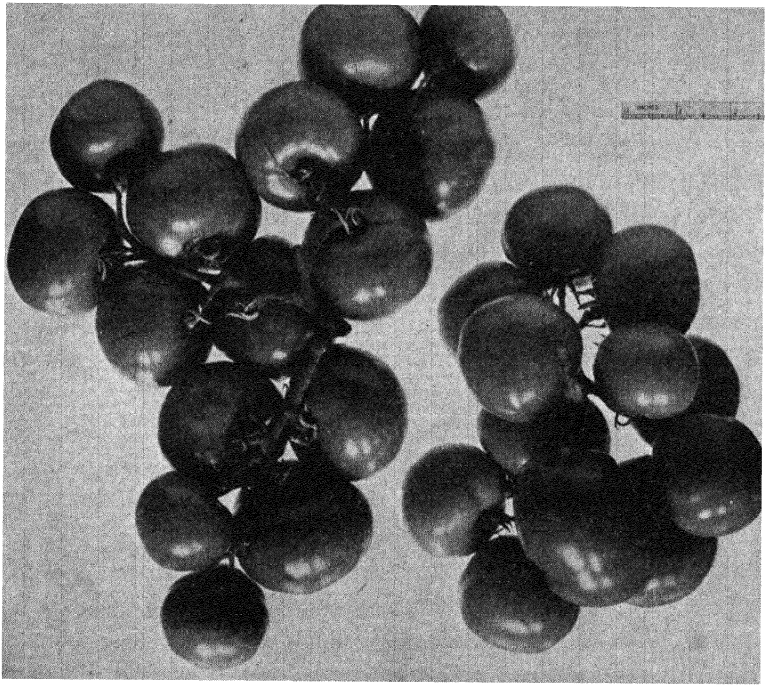

Fig. 20. Hydroponic tomatoes are firm and well colored and have exceptionally good keeping qualities. Clusters of between ten and fifteen tomatoes are common. Some are fifteen inches long.

An average plant growing in basins six inches deep, or deeper, probably cannot absorb advantageously more than a half pound of the basic chemical mixture during a single growing season. This amount cannot be mixed into the solution all at once but should be added at the rate of one ounce per cubic foot of water every month. This is only a general rule. The amounts of food recommended for addition may be doubled or the length of time between additions lessened. The climate, the variety grown, and the water used will determine which of

these two procedures is to be employed. If the setting of fruit is very heavy, or if tests show lack of nitrogen or phosphorus, plant food should be added to the solution regardless of how much foliage has been produced. The quality of the tomato fruit depends upon a continuous supply of nutrients, for fruiting is associated with continued vegetative growth rather than with a termination of that growth, as is the case with wheat and potatoes.

The upper limit of the tolerable temperature range for tomatoes is from 90 to 95 degrees Fahrenheit. A few days of higher temperatures will do no harm but, if they are maintained over a longer period of time, pollination will be checked and the plants' respiratory rate will increase rapidly. The latter effect will cause them to use up their reserves of carbohydrate and gradually to stop growing. The lower limit of the tolerable temperature range is around 45 degrees. Prolonged exposure to such temperatures will prevent fruiting. If nights are cool, the ideal daytime temperature is from 75 to 85 degrees. Tomatoes can be grown, however, in sections where temperatures run from a peak of 100 degrees during the day to a low of 50 degrees at night.

As the root system develops, the solution should be lowered progressively until an air space about two inches wide is left between the seedbed and the liquid. If you allow the solution to drop three inches or more below the seedbed and maintain it at this level for about a week or ten days, the roots will harden and, when the basin is refilled, the plants might wilt. This wilting is usually only temporary unless the roots have become adapted to air conditions. For example, the plants will recover within a few hours from the wilting produced when solutions are drained and replaced.

In regions of excessive rainfall, cultural technique requires special care in the provision of proper aeration. An overflow pipe should be placed in the basin so that you can make the air space as large as possible while still maintaining two or three inches of the roots in the solution.

Aeration of tomatoes depends largely upon the character of the seedbed. It should be constructed of coarse materials, such

as shredded cornstalks and straw, with fine litter added to fill the interstices. If too much fine material is used, the roots are likely to combine with natural settling of the bed to turn it into a semi-impervious matting. In some cases where this has happened, it has been necessary to raise the seedbed and leave a slit about a half inch wide between it and the basin top, so that enough air can reach the solution.

Growing Tomatoes in Bottles

Tomatoes can be grown to good size in one-gallon glass jars with three-inch necks. The seedlings are mounted in corks and held in place with cotton or excelsior wadding. The roots should be in the solution and the root crown in the wadding. You can fill the bottles to the top with a solution containing four grams, or one-seventh of an ounce, of the basic chemical mixture. When the plants are about two feet high and the roots have grown about eight inches down into the solution, the liquid may be allowed to drop three inches below the top of the jar.

Later, as the plants grow larger, it should be dropped another inch. Water may be added as needed, and you should add one-seventh of an ounce of nutrient each month. If growth is very rapid, you must completely replace the solution every two months, always making sure that it does not rise higher than three inches below the top. Iron will have to be added more frequently than when the tomatoes are grown in basins.

Other Vine Crops

The other vine crops—cantaloupes, cucumbers, watermelons, and squashes—like tomatoes, grow best in warm, moist regions where differences between day and night temperatures are moderate. They are sunshine-loving plants, even though they do not grow well in the intense sunlight of low humidity regions. Cucumbers have the lowest and melons the highest light requirements in the group.

The vine crops well illustrate the relationship between

quality of the fruit and variations in the supply of sunlight. Quality in the cucumber means tenderness of flesh, low sugar content, and absence of bitter elements. These properties are obtained under conditions of low exposure to sunlight. In the cantaloupe and the watermelon, quality is identified with high sugar content, a property markedly dependent upon ample sunshine. These requirements restrict cantaloupe and watermelon production more than they do production of cucumber and squash, which are grown in higher latitudes.

Notwithstanding the climatic restrictions imposed upon them as warm-weather plants, the vine crops are extensively grown. Although very susceptible to frost injury, they grow rapidly when the weather is warm. Consequently, they can be produced in regions having short summers. Some of the choicest products, in fact, are grown in regions of fairly high altitude where local factors create a favorable environment. These conditions merit close study, for they offer clues to the characteristics of vine crops.

Much research has been devoted to the selection and development of high-quality strains of the various vine crops. Unfortunately, there is very little information of this sort available on the selection of varieties suitable for hydroponic culture. Cultural technique and climatic requirements make the production of vine crops more specialized than is the case with other vegetables having an equally wide geographical distribution. Nevertheless, good-quality crops have been grown by hydroponics. By acquainting yourself thoroughly with the requirements of these crops you can grow choice products.

Root-Top Ratio

Young plants form new roots very easily, but their foliage grows at such a rapid rate that they have relatively low root-top ratios. Vine crops do not all have as great recuperative powers as tomatoes, which constantly produce new roots and shoots. The result is that a heavy responsibility is placed upon the cultural technique, which must be designed to prevent the development of conditions unfavorable for growth.

Planting Vine Crops

Litter which is close to the plants must be carefully chosen for its water-holding capacity. The remainder of the litter does not need to be so carefully chosen. The chief features to be considered in planting vine crops are:

1. The seed is susceptible to damage by excessive wetness in the litter. The seed of vine crops will be injured by a degree of dampness which would not prove injurious to other seeds.

2. The seeds should be planted about an inch above the wire netting so that the new roots will quickly reach the nutrient solution. The planting should be shallow.

3. The seedbed should be deep enough to encourage profuse lateral root development.

4. The surface of the bed immediately surrounding the plants should be sufficiently dry to prevent damping-off of seedlings and root rot of large plants—two maladies to which vine crops, particularly cantaloupes and watermelons, are very susceptible.

Preparation of the Seedbed

Litter in the seedbed for vine crops need not be of uniform texture. These crops are planted in hills and require considerable space. If choice litter is scarce, you may place two or three handfuls of it for each hill on the straw or excelsior matting lying on the wire screen. Plant the seed in this choice litter. The spaces between the hills can be filled in with less select material.

Some growers plant the seed in a small mound extending an inch or two above the surrounding litter. This provides drainage and prevents excess moisture from collecting around the seedling.

Should you already have a seedbed three or four inches thick, you may make a small hollow with your hand and plant the seed about an inch above the wire netting, covering about one-half inch with moist litter. After the plants are up you can fill in the hollows around them with litter of low water-holding

capacity. An ideal seedbed has a lower water content after the plants are up than during germination.

It was pointed out in the chapter on planting that wheat, barley, and other seeds have a great attraction for water and sprout even though the moisture content of the seedbed is too low to support the seedlings. These are seeds of high starch content and have large reserves of food for roots. The seeds of vine crops are practically all leaf material and have much lower attractive power for water. The reserve food for roots is relatively small—thus vine crops cannot start as well in too dry a seedbed. On the other hand they are more sensitive to excess moisture.

The best seedbed temperature for germination is between 75 and 85 degrees Fahrenheit. Although seed of vine crops sprouts easily, replanting is common in agriculture, owing to great mortality in cold and wet weather. Some growers pre-sprout their seed between layers of moist cloth before planting. At 85 to 90 degrees Fahrenheit these seeds will sprout within three or four days. Because the seed sprouts so quickly, it is not advisable to plant before the weather becomes warm.

Stands

Stands can be much closer if the plants are supported and trained to grow upward instead of horizontally. This is the practice commonly followed with cucumbers and cantaloupes raised under glass. You can space the plants in the same way as in growing tomatoes: twenty plants per 25 square feet of tank space. Remove the lateral branches to reduce excess foliage. Binder twine can be used on the supports. Where vines grow horizontally, more space between plants is necessary. If basin area is scarce, vines can be allowed to run over the sides and on the ground.

Supplying Plant Food

Vine crops show dearth of plant food very quickly; they do not have the capacity of other crops to store reserve, and conse-

quently nutrients should be available at all times. Add the basic formula to the water in the same quantities as given in the directions for tomatoes. This should be available when the roots have penetrated the seedbed. But more important than in the case of the tomatoes is the addition of plant food to the seedbed. This should be applied in small quantities around each plant as soon as it is up, to encourage lateral rooting. There should be ample but not excessive supply of nutrients in the seedbed. The tendency of the uninitiated will be to add too much when the plants are young. In order to appreciate what the proper amount is, remember that one ton of fertilizer per acre is a very large application in agricultural practice. This equals one pound per 21.8 square feet area. Although the basic formula has given very good results, the growth characters of vine crops indicate that a combination of nutrients containing more nitrogen would be more economical. A simple way of providing this additional nitrogen is to sprinkle small amounts of any of the nitrogen salts, except potassium nitrate, on the seedbed when the plants are twelve to eighteen inches tall. Chemicals which can be used are given in the chapter on field crops.

Cucumbers

Cucumber is more widely grown than other vine crops and requires a shorter season to produce the harvest, as it is usually picked green. Vines live longer and bear more fruit if none is allowed to ripen. Cucumbers range from the early small round forms like lemons full of seed to the late varieties such as the seedless long round English Telegraph sometimes grown as a forcing crop in greenhouses. Most vine crops are dependent on insects for natural pollination. If grown under glass, provision should be made so that bees can visit the flowers. The lack of pollination in cucumbers frequently is the cause of small, ill-shaped half-moon forms, sometimes produced in greenhouse culture or in isolated plants that bees have not visited. Mis-shapen forms vary with climate, which affects the activity of insects. Mildew, a fungus disease, sometimes is a

serious matter with vine crops. Mildew also varies with climatic conditions, and usually thrives in damp, cool conditions. Because cucumbers can be grown in cooler climate, mildew is usually more noticeable among them than among other vine crops. Although humid atmosphere is ideal for cucumbers, excessive moisture in the seedbed and wetness on the plants

Fig. 21. Cantaloupes planted one foot apart, pruned to one vine, grow upward on binder twine, bearing two or three melons weighing four to six pounds each when full grown.

when temperature is low should be avoided if possible. In regions where temperature might become unfavorable, varieties capable of excessive foliage are not so well adapted as others.

Cantaloupes

Cantaloupes require a longer season and more sunshine than cucumbers, but the vines usually do not live so long, as the fruit is picked ripe. Cassaba, honeydew, and Persian melons can be considered with cantaloupes so far as cultural technique is concerned. They vary considerably in length of season and amount of sunshine required, so that culture of these types of melons is somewhat more restricted and localized than that of the ordinary cantaloupe. Some of the choice ones are greenhouse-grown. Cantaloupes when grown as a forcing crop are more influenced by the seasonal light effect than cucumbers. It is more difficult to obtain a good set of fruit by pollination done in December and January than when the days are longer. When bees are not available, pollination is done by hand—by picking the staminate, or male flower, and sticking or pressing it on the pistillate, or female flower, which is easily recognized by the small fruit at the backs of the petals.

It is probable that in the marginal area between the regions of favorable and unfavorable climate, advantage could be taken of the reflected heat and light from surrounding objects to increase the temperature of the seedbed. By locating the basins to receive the protection of walls and buildings, it was found that cantaloupes could be grown where normally it was considered to be too cold.

Watermelon

Watermelon is generally a more vigorous plant than the cantaloupe or cucumber, but requires a longer season. Although this somewhat restricts the northern extension of its culture, nevertheless watermelon is about as widely grown as cantaloupe because of its greater hardiness once it obtains a good start. Watermelons are planted farther apart, the vines grow longer,

and the fruit is larger, but there are fewer per plant than with cantaloupes. It is not yet known whether closer planting with greater yield per area than prevails in agriculture is possible in hydroponics. The relation between number and size of fruit and the size of the vine would have to be studied to determine how closely watermelons should be planted to obtain the largest yield. As a rule only one good-sized melon will develop on a vine, but a plant can produce several large vines each bearing a melon. The first fruit to set gets the start so that it prevents others from developing on that vine. It is assumed that the melon which gets the start draws all the nourishment of the vine, leaving none for other fruits that set later. It is this condition which makes it so difficult to determine the mineral requirement of the melons. The relation between weight of fruit and extent of vine varies markedly among vine crops from which fruit is picked ripe.

Squashes

The most vigorous and hardy of the vine crops are the squashes, of which there are a great many varieties. They are grown both as green and as ripe vegetables, and are among the earliest and latest of vine crops. Summer squashes have restricted vines and are planted much closer than those which have long vines, such as the Hubbard squash. The summer squashes are about the easiest of the vine crops to grow by hydroponics.

CHAPTER NINE

Potatoes

Most American growers consider the potato a cool-weather crop. This is not always the opinion of others who raise this crop in regions where high early summer temperatures are unknown. Foliage of the potato is damaged by frost which would not prove serious to root crops, such as beets and turnips, or to cereals like wheat, rye, and barley. So it cannot be designated as a crop especially adapted to cold weather.

No other major field crop, with the possible exception of wheat, has as wide a geographical distribution. Nor can any of them equal the potato's ability to grow well under a wide range of latitudes, elevations, and purely local influences. In the United States the largest yields (in excess of 1,100 bushels per acre) have been taken from land below sea level and more than a mile above. Yet in the face of this evidence the potato is not so universally suited to various kinds of soil and culture as are other crops more restricted by climatic influences. It is the most extensively grown garden or field crop in northern countries and a neighbor of cotton, rice, and sugar cane on southern plantations. But many farmers give more thought to the selection of suitable land and location for potatoes than for any of the other major crops. Now by hydroponics, which has eliminated the soil, the full geographical potentialities of the potato may be fully realized. The potato's wide adaptability is based upon certain physiological characteristics:

1. Compared with other field crops, it requires a shorter period for development of foliage, hence can be grown in high latitudes where short summers prevail.

2. The relatively long period required for young plants to appear above the ground after planting provides a measure of protection against late spring frosts which is lacking among quick-sprouting crops of equal growth period.

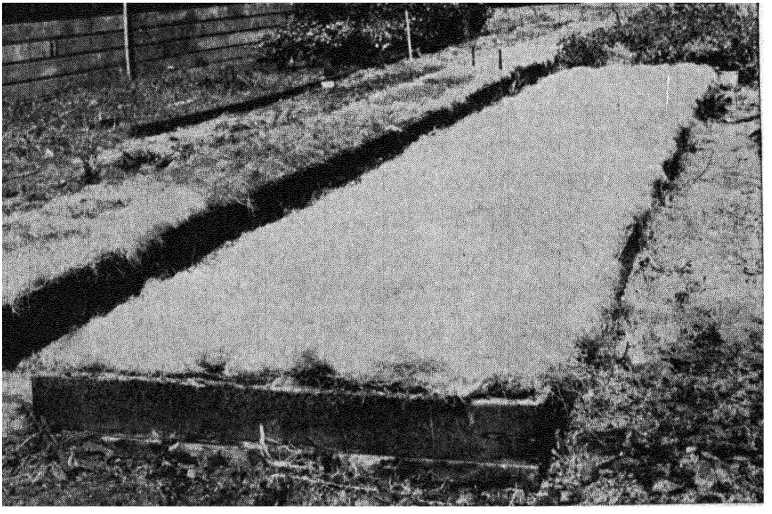

Fig. 22. Seedbed ready for potatoes. The seed pieces are placed in the litter and covered. If seedbed is already complete, the seed potatoes can be inserted in the litter about three inches deep.

3. Hastened maturity does not necessarily lower the quality of the tubers, though it curtails size and yield.

4. The crop can be harvested before maturity. Thus, injury to foliage and stoppage of growth due to early frost are not so serious as in the case of other crops which must have mature vegetation before they are of use.

5. Finally, the crop need not be harvested when it is mature. It is not uncommon to leave potatoes in the ground for months after they are ripe. The only stipulation is that they must be harvested before cold weather, excessive heat, or rain sets in.

From these characteristics we see that potatoes are adapted to high latitudes because of their short growth period. They are also well suited to high elevations because the warm sunshine in these regions is ideal for photosynthesis and the cool nights provide the tubers with ample opportunity to store photosynthetic products in the form of starch.

While partly economic, the reasons for concentration of potato production in certain areas are found chiefly in soil-climate combinations. It is a fine-, shallow-rooted crop which grows best in well-aerated and well-watered soil. However, the determining factor is the root temperature, which depends not only on the climate but also on the physical properties of the soil. A few hot days of 90 degrees or more when the crop is just appearing above ground will curtail root development. Also, unusually high soil temperatures at the time when tubers are forming will curtail the yield. The high-yielding areas all have one common characteristic in that temperature in the tuber zone can be held within required limits even though air temperatures are high. In hydroponics the seedbed must be so constructed that similar conditions are maintained.

Experiments conducted in 1933 showed the importance of covering the tubers with an adequate thickness of vegetable litter. Three basins were seeded to potatoes and the seed covered with a mixture of straw, sawdust, and shavings to depths of one, two, and four inches. The nutrient solution was protected from the sun by this litter and did not rise above 70 degrees Fahrenheit, even when air temperatures rose to 105°. The surface of the litter on these hot days soared to a temperature of 100 degrees or more; loose, dry material became hotter than that which was moist and compact. The shallow bed was warmest at the level of the tubers and the deep bed coolest. The yield from the deepest bed was 2.4 pounds per square foot; that from the two-inch covering was 0.5 pound; and that from the shallowest bed was only one ounce.

The temperature of the seedbed at its surface is the result of direct radiation and, to a minor degree, conduction of heat from surroundings. That of the bed's interior is determined primarily by conduction. Because of the high specific heat of

water, the temperature of seedbeds having a high water content will be more constant than that of those which are relatively dry. The differential in temperature between the tops and the tuber zone is primarily the result of the amount of water held in the litter and the quantity and character of the litter used. The shallower the seedbed, the warmer will be the tuber zone when high temperatures prevail at the surface.

The potato can stand very hot weather so long as the tuber zone is kept cool. This is evident from the surprisingly large yield obtained from the four-inch bed in the experiment described. This test was carried out in a greenhouse where the temperature was too high for wheat. The vines were six feet long at harvest. Unless there is a special reason for it, potatoes should not be grown in a greenhouse. Usually, the nights will not be cool enough or the days too hot. They require direct sunlight, so it is not practicable to shade the greenhouse in order to keep temperatures down on hot days. So far as length of vines is concerned, three feet is ample for most vigorous varieties. You should strive for sturdy stalks rather than long ones.

Description of another experimental set-up will help you understand the methods to be used. A layer of excelsior about an inch deep was placed on wire netting. Seed tubers were placed on the excelsior and covered four inches deep with a mixture of old excelsior and new wheat straw. As this material was quite open, sawdust was worked into the bed to increase its density. The coarser material prevented the sawdust from packing together and provided good conditions for aeration. Owing to the quantity and type of the litter, the seedbed had high water-holding capacity and good drainage. The seed was sown one to every 84 square inches, which was probably a little close for the variety and season. The yield from this basin was comparable to 1,800 bushels from an acre of soil.

Detailed Instructions

The following instructions as to how to grow potatoes by hydroponics are based on experiments conducted since 1934.

In these experiments it became apparent that climatic conditions play an extremely important role in potato production. It appears probable that a satisfactory technique can be developed to fit the climate in any region where potatoes are now grown.

You should take care that your basins are not too narrow. Those six feet wide and ten feet long are a good, practical size. If the available area does not permit basins this large, they should be made shorter rather than narrower.

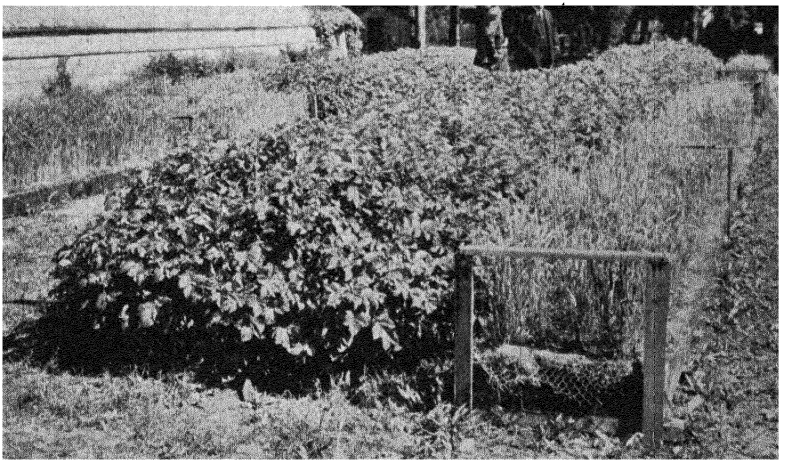

Fig. 23. Potatoes twelve weeks after planting and eight weeks after the plants were up. Spacing was at the rate of one plant per 100 square inches.

The potato does not require pollination and can be mass planted. This type of planting affords protection against wide fluctuations of temperature in the tuber zone.

In preparing the seedbed for planting, first place a matting of excelsior, one inch deep, on the wire netting. If it is spread thoroughly, even a half inch will do. Dry straw or hay can also be used, or, better yet, decomposed straw or hay. If the dry material is used, a two-inch layer will suffice. The purpose of this coarse litter is to keep the finer litter from falling through into the solution and to surround the seed-pieces with porous material.

The seed should be of a good variety commonly grown in your section. Size is not important. Small tubers about the size of small eggs can be used whole. Large tubers should be cut into pieces weighing from one to two ounces and containing one or more buds (eyes). If the weather is cool, you may plant the cut pieces immediately. Usually, however, it is good practice to allow them to stand for a few days, protected from the direct sunlight, so that they have time to form a callus over the cut surface.

Fig. 24. Close view of 23. Measurement by the yard stick shows the plants to be 3 feet high twelve weeks after planting.

Place the seed-pieces directly on the excelsior. The spacing between them will depend upon variety and climate. Varieties that tend toward long vines should be spaced farther apart than those having short ones. Also, the spacing should be wider in moist, humid climates where cloudy days are frequent than in dry climates where bright sunshine is common. In the cool, moist regions, spacing is designed to provide the most favorable exposure to light while in the hot, dry climates it is aimed at giving protection from excessive root temperatures. Spacing of one plant to every 80 square inches is not too close for varieties

whose foliage can be held under thirty inches in length, but is too close for the long-vined plants. From one-half to two-thirds of an inch in diameter is a good thickness for stalks of varieties of proved productive capacity.

After placing the seed on the first layer of litter, cover it with another. If you have straw, shredded cornstalks, or dry vegetable refuse, spread it on to a depth of two inches. An equally deep layer of excelsior packed tightly might prevent the young

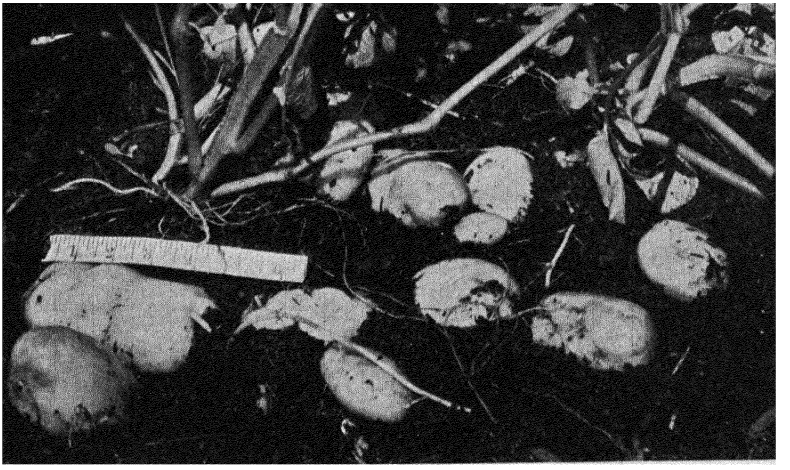

Fig. 25. The potatoes form in the seedbed litter. They grow at the ends of stolons which grow out laterally from the root crown. The litter has been removed so that they can be seen plainly in the picture.

plants from coming through if enmeshed by the strands. Then add sawdust, shavings, or decomposed litter to fill the interstices of the bed.

The depth and weight of the litter above the seed pieces will depend upon the materials used and the climate. Assuming that you start with new, dry material, the bed will probably be quite open. Therefore, it will be well to scatter some soil on top of it. Light, sandy soil is the best, though other types may be used. It is not necessary to add so much that the litter is completely covered. Simply scatter a shovelful here and there. A bed four inches deep after it has settled, of which a half-inch or less is soil, will be suited to most conditions. The bed should

be deeper in hot climates than in cool. In regions where rainfall is heavy and constant, coarse litter should be used, so that excess water will drain from the bed rapidly.

In the second planting season you may again use the old litter, which will by this time have been partially decomposed and converted into finer seedbed material. If it has disintegrated into finer material, first place a layer of straw or excelsior on the netting, plant the seed pieces, and then cover them with the old litter. New material, such as sawdust, shavings, or lawn clippings, can be thrown on top.

The bed must be kept moist so that the seeds receive plenty of water for germination. You can fill the basin with water and allow it to come in contact with the litter until it is thoroughly soaked. The water level must then be lowered to allow the excess in the bed to drain out. If the litter has been properly blended from coarse and fine materials, excess water will drain out in a day or two. The bed may also be sprinkled from the top. Such occasional soakings of the seedbed do not harm the potatoes so long as the free water drains away into the basin.

When planting is done in early spring and the seed stock is firm without sprouts, four to six weeks will be required for the plants to appear above the surface. If planting is later, when the weather is warm and the seed is aged, the plants appear within two to three weeks. Usually, firm seed gives the best stand. You will be wise in planting a few extras in the bed. These can be used as transplants in case some seed fails or a few of the plants are weak. Such plants should be removed from the bed. In transplanting, simply lift the plant and attached litter bodily and set it down in its proper place.

As soon as the plants are up, you should add plant food to the water in the basins at the rate of one pound of the basic formula for every 125 gallons of water. It is assumed here that the water used will not contain more than 200 parts per million of natural solutes. You should also add one pound of the basic mixture to every 25 square feet of seedbed. This can be scattered by hand among the plants. There is no advantage in adding nutrients either to the solution or to the seedbed at the time of planting. If added to the bed, the chances are they

would draw water out of the seed-pieces and thus reduce their germinability.

Keep the basin full of solution at first, but do not allow it to touch the seedbed. Arrange the overflow pipe so that the air space between solution and seedbed will be between one-half and one inch across. If excessive temperatures have not harmed them during sprouting, the plants will make a thick mat of

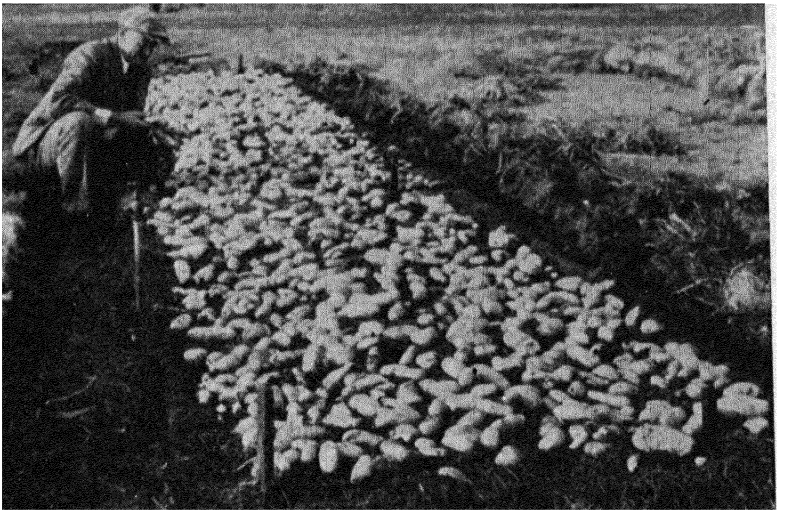

Fig. 26. Choice potatoes produced by hydroponics. From 60 to 70 per cent of the seedbed was covered with tubers. The yield for 1/100 acre was 1482 pounds.

roots two to four inches deep into the solution. But, if the weather has been too hot and the litter too open, the roots will not grow downward. Then it will become difficult for the crop to absorb enough water and food.

The plants will not sprout evenly as do corn and wheat. A week or more will be required after the first ones have thrust through the top layer of litter before all of them will have appeared. This is because the buds on the tubers are not all equally mature and do not have equal amounts of growth-stimulating substance. Under ideal conditions the plants can

grow a foot per month. After the first month has passed, you should add another pound of plant food to the solution, provided the roots are well established in the liquid. If they are not, the mixture can be scattered on top of the seedbed. It will ultimately dissolve into the litter and the solution. There will be no injury to the potato leaves if the nutrients are washed down immediately after application. In regions of excessive rainfall, you will find this the best way to add plant food. After

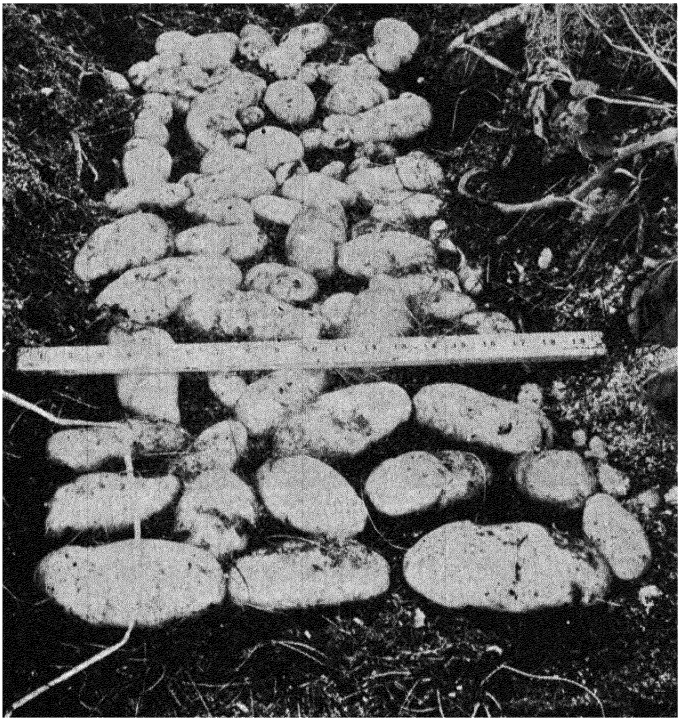

Fig. 27. Hydroponic potatoes grow to uniform size if cultural conditions are ideal. The quality is markedly influenced by moisture content of the seedbed when the crop is maturing. When the tubers are nearly their full size and the vines begin to show yellow, the solution should be lowered so the seedbed can dry out slowly. By duplicating the moisture conditions of well-drained sandy loam soil, the highest-quality potatoes of agriculture can be produced by hydroponics. If the seedbed is too wet, the vines may ripen prematurely with some loss of crop, or the ripening may be prolonged, resulting in loss of quality.

the second month has passed, another pound of chemicals should be added. Four pounds are sufficient to grow all the potatoes seeded in an area of 25 square feet (or a basin ten feet long by two and one-half feet wide), so long as there is no loss except by absorption. Of course, this applies only when the potatoes are grown alone.

If growth is very rapid, the plants will probably show symptoms of iron deficiency. These will appear as light yellow spots on the newest leaves. To overcome the lack of this element, you should add one quart of a one per cent iron sulfate solution to the seedbed. It should be added in several places, and it must not be allowed to come in contact with the foliage.

The tubers form in the seedbed, and will not grow in the solution. The litter also protects them from light, which would turn them green. They form at the end of stolons which grow laterally from the root crown. As the crop begins to mature, you should lower the solution in the basin. This will dry out the seedbed and improve the quality of the tubers.

The life of the plant can be extended several weeks by added applications of chemicals during the latter growth stage. This practice is not recommended, however, for while it may increase the yield, the shapes, of the tubers are impaired. The growth period can also be shortened by excessive temperatures but this will reduce the yield. You should grow each variety for its normal period. For White Rose (also called Pride of Wisconsin), the variety used in the experiments, the best yield and quality are obtained when the crop grows about 120 days from seeding to maturity. The normal growth period of standard varieties ranges from about 100 to 140 days.

Sweet Potato

The sweet potato is a warm-weather plant which grows well by hydroponic culture. It requires a seedbed four or more inches deep which can be of coarse materials such as straw or shredded cornstalks. As the crop does well in regions where sugar cane is grown, bagasse, the crushed cane stalks after milling, will probably prove satisfactory as a seedbed material.

The sweet potato is started by placing the seed tubers to sprout in a flat of light soil or coarse sand that is kept moist. When the sprouts are several inches high, they are removed with what roots they have and planted in the litter bed. It is not necessary to insert the roots in the solution, but if immersed they will grow readily. Sprouts without roots can also be planted satisfactorily. In warm regions, such as the cotton and sugar cane belts, sprouts can be obtained by planting the seed tubers in the litter.

The best spacing for the sweet potato is not known. It has a high light requirement and therefore the largest yields are not obtained from plants that have rank vines. It is a crop that is easily over-fed. A spacing of one plant per square foot has been found satisfactory.

The relation between yield of tubers and foliage varies more than in the case of potatoes. This has made it more difficult to appraise its plant food requirement. The growth structure and habits of the sweet potato indicate relatively low plant food requirement.

Sweet potato is a good crop with which to conduct experiments on the following points:

1. The influence of potassium, nitrogen, calcium, magnesium, and phosphorus on yield and quality by technique described with wheat in the chapters on field crops and mineral composition.

2. The influence on yields of pruning the vines.

CHAPTER TEN

The Root Vegetables

THE ROOT vegetables, most common of which are carrots, turnips, beets, parsnips, and radishes, are so-called because, as they develop, their tap roots enlarge and change from absorbing to storing organs. For example, the edible portion of the carrot is really a root, but it is one which has lost the power to gather mineral nourishment for the plant and is instead devoted to storing up a reserve of materials fabricated by the leaves. The task of gathering food for the plant is performed by small, thread-like roots growing from the storage root itself.

All the root vegetables mentioned have been grown by hydroponics. Each requires a more or less specialized technique. As in the case of potatoes, the storage roots do not develop to size when immersed in liquid. They develop in the seedbed with the feeding roots, which grow from them, penetrating down into the solution and drawing food from it. Cultural technique should be designed to localize feeding roots to the tip end of the storage root. This will help to produce clean, smooth, well-formed vegetables.

The distance which the roots must penetrate before reaching the solution, and the character of the litter through which they must force passage, influence the size and shape of the storage organ. The natural length of the fully developed storage root will determine the depth of the seedbed.

If the seed is planted too near the solution, the feeding roots will enter too soon. This will result in the formation of a

pencil of rootlets of approximately equal size. The natural consequence of this development is that the plants no longer have one root definitely leading the downward penetration, as is natural when they grow in soil. The storage root then becomes flat and stubby. On the other hand, if the seed is planted too shallow, the roots have too far to go before reaching the solution and the plants are weakened.

Root crops are generally considered to be cool-weather plants. This is not a matter of geography, for they are grown widely, but of climatic conditions. Normally these plants, except for the radish, are biennials; that is, they produce seed in the second year after planting. Nevertheless, if temperatures are too high, they may produce seed the same year they are planted. They rapidly lose quality when they begin to produce seed stalks.

Uninterrupted growth is extremely important if root vegetables of high quality are to be produced. These vegetables are not particularly high in sugar or starch content, as compared to sugar beets or potatoes, nor do they contain a high percentage of mineral salts. Consequently, quality is not so much a question of the amount of actual food material they may contain, as of the texture of their flesh. When growing conditions are such that growth is not continuous but instead a stop-and-go development, the vegetables become coarse-textured. They lose their sweetness and tenderness. In production of these crops, climatic and cultural conditions play a very important role. However, good root vegetables can be grown by hydroponics anywhere that they are now produced from soil. In fact, they can be grown by soilless methods in regions too warm for their production by agriculture.

Planting Root Vegetables

Root vegetables can withstand frost and thus can be sown early in the year when the temperature of the litter is about 50 degrees Fahrenheit. However, the character of the weather they will encounter within the next few months, rather than their tolerance for cold, should determine the date of planting.

Where hot summers prevail, planting should be done early and at such a time as to insure three to four months of subsequent favorable weather. Temperatures ranging from 65-80 degrees Fahrenheit during the day and from 50 to 65 degrees at night are ideal. Such weather will give a temperature of from 60 to 70 degrees in the main body of the seedbed. Once the vegetables are well established in the solution, they can withstand higher temperatures.

Seed of root vegetables should be sown shallow, not more than one-half to one inch below the surface of the litter. Radishes usually appear above the seedbed first, followed in order by turnips, beets, carrots, and parsnips. The depth of planting and the moisture content of the seedbed may alter this order. Radishes and turnips start more quickly in litter low in moisture than do the others because their round seed gives better contact with the moisture and has a greater absorbing power than does seed that has a hard husk, like that of beets.

Carrots and beets can be sown so closely that their storage roots touch when full-grown. This means forty to sixty plants per square foot for medium-size varieties. Turnips and radishes will do well with a stand of six to ten plants per square foot. Parsnips require more room because of their large leaf spread.

Root Crop Yields

All root vegetables but the parsnip can be used before they are fully developed. By thinning them out when they are large enough to use you will give the remaining plants a chance to develop to larger size. Yields of three pounds per square foot have been obtained with all root vegetables but the radish. These yields were obtained with medium-size varieties and can be exceeded with the longer varieties if these are allowed to develop to full size. Unless fully matured at harvest, hydroponic vegetables usually wilt faster than do those grown in soil, but when eaten fresh, their table quality is correspondingly superior. Fully matured root vegetables grown by hydroponics keep fully as well as do those which are soil grown.

Parsnip—Hardest to Grow

Of the vegetables named, the parsnip is usually the hardest to grow. There are several reasons for this. In the first place, it requires a longer time to develop to size and thus is longer exposed to the danger of interrupted growth. Secondly, it has long storage roots and therefore requires a deep seedbed. This adds to the difficulty of starting the crop because the seed is sown at the surface of the seedbed and the roots then have a considerable distance to go before they reach the solution. Thirdly, the parsnip root is naturally more irregular in shape than the beet or carrot. Hydroponic conditions may be such as to accentuate this irregularity. Finally, the storage root develops below the level at which the seed is planted and will be constricted or stunted by the wire netting, unless the mesh is rather large.

When growing parsnips, you should prepare the seedbed so that it will be moist while the young plant is getting started but dry after it has become well established, so that side roots will not develop. Young parsnip seedlings do not have the penetrating power of such plants as corn. Yet a deep seedbed is required so that the storage root will grow as it does in soil. Consequently, the litter should be quite firm. Decomposed litter will fill the requirement. If this is not available, earth may be mixed with new litter. Two inch mesh wire is recommended if decomposed litter is used. If not, one-inch mesh will be satisfactory, so long as the seedbed is at least 4 inches in depth.

Unless planting is on a large scale, parsnip seedlings might be grown in soil and then transplanted to the litter seedbed. Transplanting might be done in the usual way when the plants are three to four inches high. This would do away with the difficulty of starting parsnips from seed in a deep seedbed.

Parsnips can also be grown in a shallow seedbed which is deepened by additions of litter after the plants are about six inches tall. When the litter has settled (and this settling can be hastened by sprinkling the seedbed), the plants can be raised two or three inches and the root crown brought flush with the

surface of the bed. This will break lateral roots but is not harmful so long as the plant has a sufficiently large pencil of fine roots leading from the tip of the storage organ into the solution.

Carrots

Next to the parsnip, the carrot requires the most care. Short and medium long varieties (measured by the length of the storage organ) can be grown in seedbeds three inches deep. One-inch wire mesh will be satisfactory. Larger mesh will be needed for long varieties so that the storage roots can develop below the surface of the seedbed, but above the solution which should be lowered as required.

Carrots germinate readily but their roots have little pene-

Fig. 28. In hydroponics, carrots are planted much closer than in agriculture.

trating power in coarse litter. Consequently, the litter in the seedbed should be quite firm; that is, it should contain a rather large proportion of fine material. Occasional sprinkling will help pack down the litter. At the same time you should not select litter that will remain moist for long periods of time, since this induces the development of side roots. In climates where rains are frequent, use litter that drains quickly. In dry climates you can prevent litter of high water-holding capacity from remaining too moist by lowering the level of the solution in the basin after the storage roots have gained considerable size. Then the lateral roots will be destroyed. These fine roots do not offer serious trouble until the carrots have gained edible size. A dry seedbed after the foliage is four to six inches high and the storage root one-half inch or more thick, provides ideal conditions for development of a superior crop.

The shape of the root is more important in carrots than in other root vegetables. Long varieties naturally do not shape well in heavy soil because of the resistance to elongation of the root. But in hydroponics lack of sufficient resistance in the litter prevents the root from elongating downward by the development of an abnormally large lateral root system. Also, the pencil of fine roots which develop at the end of the storage root, as the plant becomes established in the solution, retards its downward movement. Thus, hydroponics produces stubbier carrots than does agriculture. The stubbiness is more serious when naturally short varieties, such as French Forcing, are grown than when longer ones—Oxheart Chatenay, or Nantes—are used. Long varieties can also be produced by adding more litter when the plants are about six inches tall.

Beets

The edible roots of beets develop largely above the level of seeding; hence shallow seedbeds built on one-inch mesh wire netting can be used. These plants are well adapted to hydroponics. The seed germinates readily, young plantlets do not develop as many spreading side roots as carrots or parsnips, and the downward development of the storage root is better adapted

to soilless culture. The pencil of fine roots from its tip does not deform the globular-shaped beet as much as it does the conical-shaped roots of such plants as the carrot.

Beet seed actually consists of a little cluster of several seeds joined together by a hard husk. Consequently, more than one plant will usually appear from the spot where a large seed has

Fig. 29. Red beets are planted thickly. Note a mat of fine roots at the tips—a characteristic feature in hydroponic culture.

been placed. You should naturally avoid having the stand of plants extremely dense. However, it is possible for three or more plants to stand together in one clump and develop good form and size. This is due largely to the fact that the beet develops above the plane of seeding.

Turnips

Turnips grow well under hydroponic conditions, but are more vulnerable to unfavorable temperature conditions than are beets or carrots. The edible root of the turnip develops

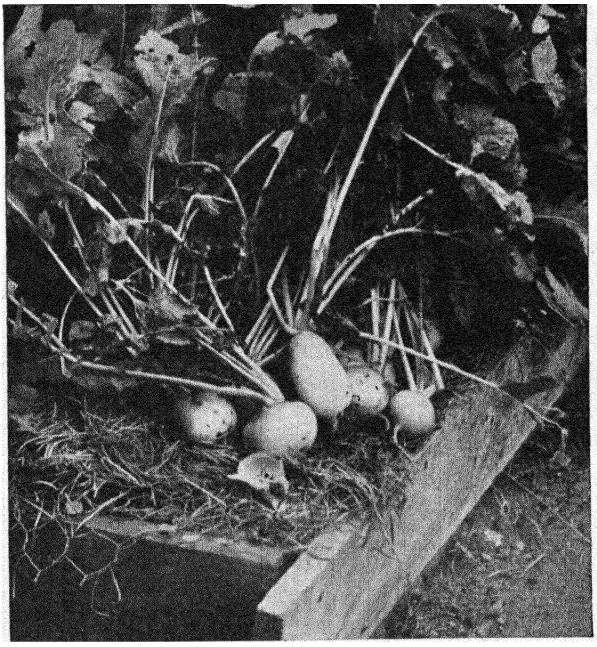

Fig. 30. Hydroponic turnips are tender and sweet if growth is not checked.

largely above the plane of seeding. It does not produce side roots, and the size of the pencils of fine roots from the end of the storage organ is negligible. Accordingly, the nature of the seedbed litter has relatively less influence on the form of the root. A seedbed two inches deep is ample. Probably your main difficulty in growing turnips will come in supplying them with iron. Their lack of side roots makes it relatively more difficult for them to absorb sufficient quantities of this element than is the case with other root vegetables. Furthermore, the turnip grows rapidly, and its comparatively large leaf spread exposes the plant to the destructive action of light on iron more than is the case with carrots.

Radishes

Radishes can be grown with the same cultural technique employed for turnips. The seedbed should be two inches deep.

The long radish varieties usually are not allowed to grow to their full size. Consequently, one-inch wire netting can be used.

Supplying Nutrients

Add the basic formula to the basin at the rate of one-tenth of one per cent of the weight of the water used. The chemicals can be added either before planting or after the seed has sprouted. This amount of the basic formula will carry carrots, beets, and turnips to about one-fourth their full size. Radishes will develop even more. Two more applications of chemicals of the same size as the first, given about one month apart, will then carry the plants to maturity.

Surface rooting should not be encouraged in root vegetables. For that reason, nutrients should not be added to the seedbed after the storage roots have started to develop. Before that time, however, a beneficial effect can be obtained by applying some chemicals to the litter. If you are able to dry out the seedbed at will, so as to destroy any fine surface roots that may appear, you can apply as much as one pound of the basic formula to each twenty-five square feet of seedbed surface. Whether or not this will prove helpful will depend largely upon your own judgment in regulating such applications to feed the crops without obtaining an undesirable surface root development.

Aeration and Iron Deficiency

Under good weather conditions, root vegetables present no special aeration problems. However, they cannot stand much moisture in the litter. A dry seedbed provides ideal aeration after the roots are well established in the solution and the liquid has been allowed to recede several inches below the top of the basin.

The cool weather conditions under which root crops thrive are also those under which iron is easily absorbed, because of the production of new roots. When warm weather sets in with its attendant bright sunshine, iron deficiency symptoms usually appear. Radishes show them first, followed in order by turnips,

beets, carrots, and parsnips. When the symptoms appear, simply add iron to the solution. The plants which show the symptoms first also respond quickly to corrective measures.

Onion

Although not a root crop, the culture of the onion can be considered with this group of vegetables. Onions can be grown wherever any other common vegetable is raised; however, their culture is somewhat specialized as far as high yields and unique qualities are concerned. The chief feature of the areas noted for onion culture is the good aeration provided in the physical character of the soil when the season is wet and cool. A hardy plant, it can stand frost as well as warm weather. It is, however, quite susceptible to damage from various causes such as plant diseases, insects—chiefly thrip and decay when the soil is wet or weather too warm.

In growing onions by hydroponic culture, you can start from seeds or dry sets—small bulbs, or seedlings. When starting from seed, follow the procedure already outlined. If starting from dry sets, follow the procedure outlined in Chapter XVI, on bulbs, corms and so on. When green seedlings are started, follow the general outline for transplants and rooted seedlings described in other chapters.

Dry bulbs are the sets you buy in the seed houses for spring planting. In mild climates, seed can be sown in the fall and the crop carried to maturity the next year without resetting the bulbs.

Figure 31 shows how closely onions can be grown by hydroponics. The seed was sown the first of September in a litter bed two inches thick. By December they had produced small bulbs. The plants were allowed to dry, and the bulbs thinned in January to give the stand as shown. The yield was three pounds per square foot. Two pounds of plant food were added to the basins ten feet long and two feet wide. A light sprinkling of plant food was added to the beds when the plants started growth anew in January.

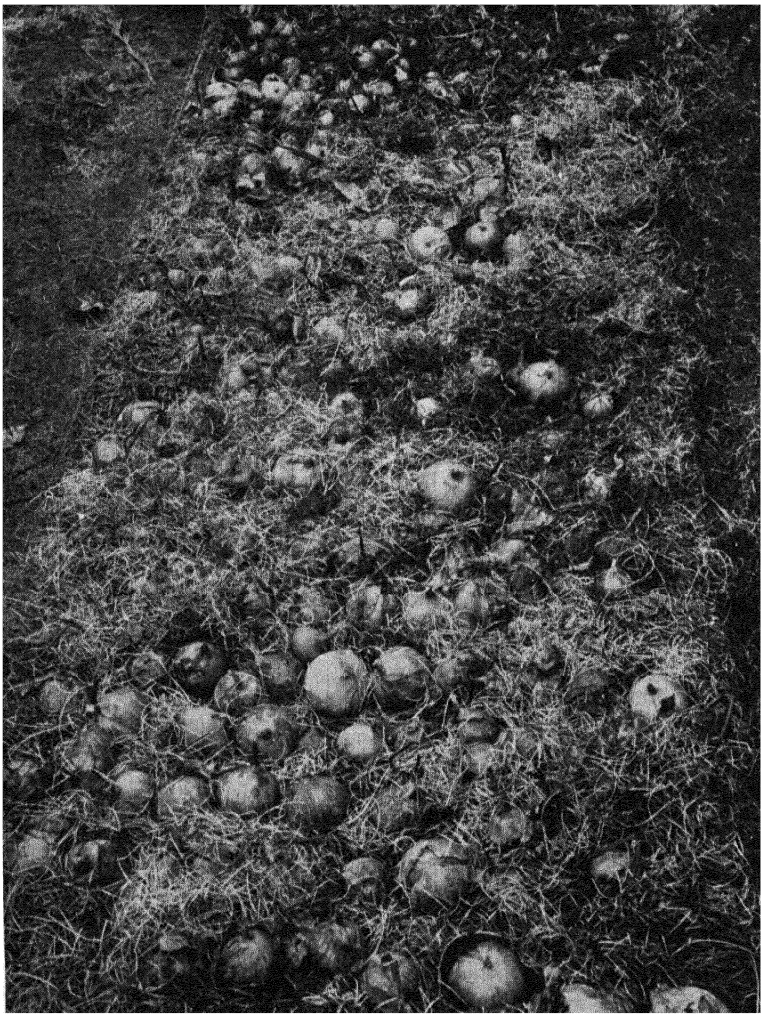

Fig. 31. A bed of onions—an easy crop to grow.

CHAPTER ELEVEN

Leaf Vegetables

LETTUCE, spinach, chard, parsley, endive, collard, and cabbage are the vegetables commonly grown for their leaves. They are valuable in the diet because of their mineral and vitamin contents, both of which are influenced by the amount of sunlight the plants receive. Leaf vegetables of superior quality require constant but not intense sunlight. The regions which have shown themselves ideal for the production of these vegetables are those where fog and haze reduce the intensity of the sunlight in summer months, thus creating a cool climate. They are winter crops in regions of mild climate.

The leaf vegetables listed in the approximate order of their resistance to injury by cold weather are: parsley, chard, spinach, cabbage, collard, endive, and lettuce. The order is determined mainly by the fact that slow growth which is induced by cold weather does not harm the quality of parsley, chard, and spinach so much as it does the others. It is not based on the relative resistance to injury by freezing. Leaf vegetables, particularly those eaten raw, should be planted in anticipation of the season that will bring about the most rapid growth. Seedbed temperatures of from 60 to 70 degrees Fahrenheit will insure satisfactory growth.

In practice, when the seed is planted, the temperature ranges from about 50 to 80 degrees. Planting at low temperatures in spring is in anticipation of warmer weather required for rapid growth, and at higher temperatures in summer in

anticipation of cool weather in the fall, which is required when the crops are ready for harvest.

Leaf vegetables are the most perishable of all garden vegetables. A few days of unfavorable weather when lettuce or cabbage are ready to harvest, will greatly impair their quality. Maturity in leaf vegetables is measured by the attainment of size, or some other distinctive characteristic, such as color, flavor, or succulence. In head lettuce or cabbage it is that stage of leaf growth which immediately precedes formation of the flower stalk. All leaf vegetables lose quality when the flower stalk begins to be formed. This formation is hastened by unfavorably high temperatures.

Planting Leaf Vegetables

Cabbage and collard are usually started from seed in soil flats. The seedlings are transplanted to the litter seedbed. The same procedure may be followed with the other leaf vegetables but is not necessary. They can be sown either broadcast or in rows with about a half-inch covering of the seed in a litter seedbed two inches deep.

It is rather hard to recommend any rate of seeding for leaf vegetables, since they can be used in various stages of their development. The largest plants can be used first, and their removal makes more room for the development of those remaining. Moderate crowding is actually desirable in planting leaf lettuce, parsley, spinach, and endive, because it produces plants with tender leaves. All the leaf vegetables but cabbage and collard can be planted at a rate of twenty to thirty plants per square foot, and gradually thinned.

All leaf vegetables except chard have a fairly small seed and consequently thin roots. These roots center around a rudimentary lead or tap root, which naturally grows downward. If the seedbed is too deep, the weak roots are easily diverted and the plant fails to become established in the nutrient solution. On the other hand, the seedbed must not be too loose and open or it will not hold the water and nutrients required by the plants. It is your task to devise a seedbed made of a

mixture of materials which will be not too open, but at the same time will allow the weak roots of the vegetables to penetrate it. Seed sown within an inch of the wire mesh in a properly constructed seedbed will normally produce roots capable of crossing a half-inch air space into the solution below.

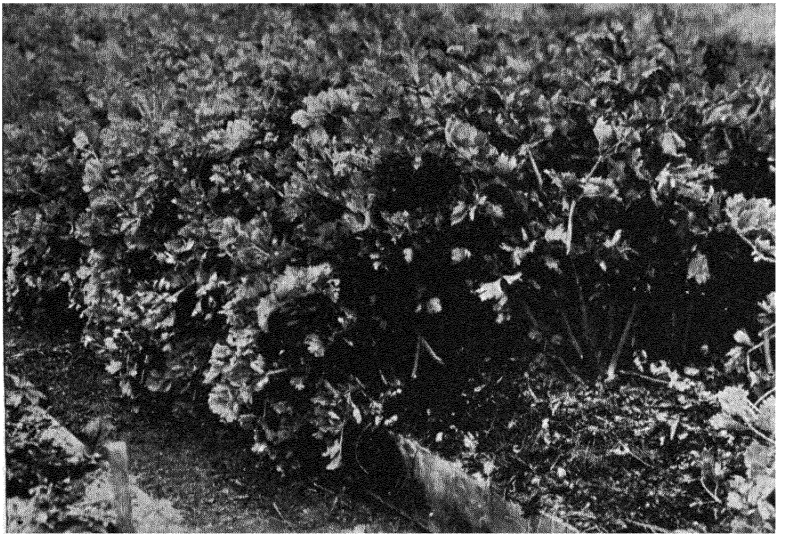

Fig. 32. Celery.

Leaf vegetables as a whole are shallow-rooted plants and quickly suffer from lack of aeration if the seedbed becomes too wet. Their ability to develop surface roots should be encouraged but not at the expense of the roots in the solution. The roots should be established in the solution by the time the plants have four or five leaves. If they are not, the reason is usually found to be that: (1) the seedbed is too wet, (2) there is too much plant food in the seedbed, or (3) the temperature at the surface of the seedbed is too high.

Additions of plant food to the seedbed will encourage root growth. For crops sown broadcast, the nutrients may be added before seeding. Or they may be dissolved in water and sprinkled over the bed after the plants are up. If this method is used, however, the solution should not be more concentrated

than one-half ounce of the formula for every gallon of water, and it should not be applied until the plants have three or four leaves. When the plants are spaced far enough apart so that the chemicals will not fall on the young leaves, dry nutrients may be applied at the rate of one pound of the basic formula for every twenty-five square feet.

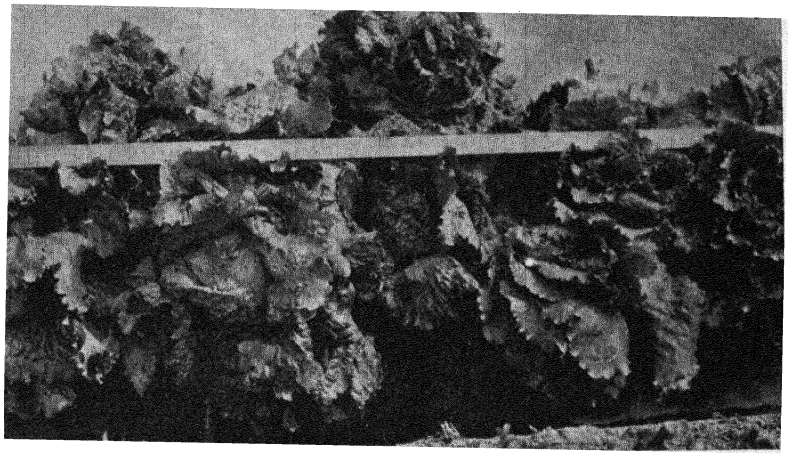

Fig. 33. A bed of head lettuce. If the surface of the seedbed cannot be kept dry, this planting is too thick.

Leaf vegetables do not produce so much vegetation as do most other crops and consequently do not need so much food. At present the exact amount needed is unknown. Until experimental data on this point are available, you may feel safe in using about one pound of the basic formula for every 125 gallons of solution, in addition to that added to the seedbed. This will be enough to bring all leaf vegetables except cabbage and collard to usable size. Whether more will be needed depends upon the size to which the plants are allowed to grow.

Head Lettuce

Lettuce is one of the most widely grown of all vegetables. There are several distinct types of this variety which require special growing conditions. Most important of these is head

lettuce. Hot weather (85 to 100 degrees Fahrenheit) prevents heading, too much water causes the heads to burst, and too humid conditions around the base of the plant stimulate leaf rot. Nor can head lettuce be crowded together as other vegetables are. Too close a stand of head lettuce invites decay. Under ideal conditions for producing large heads, the plants

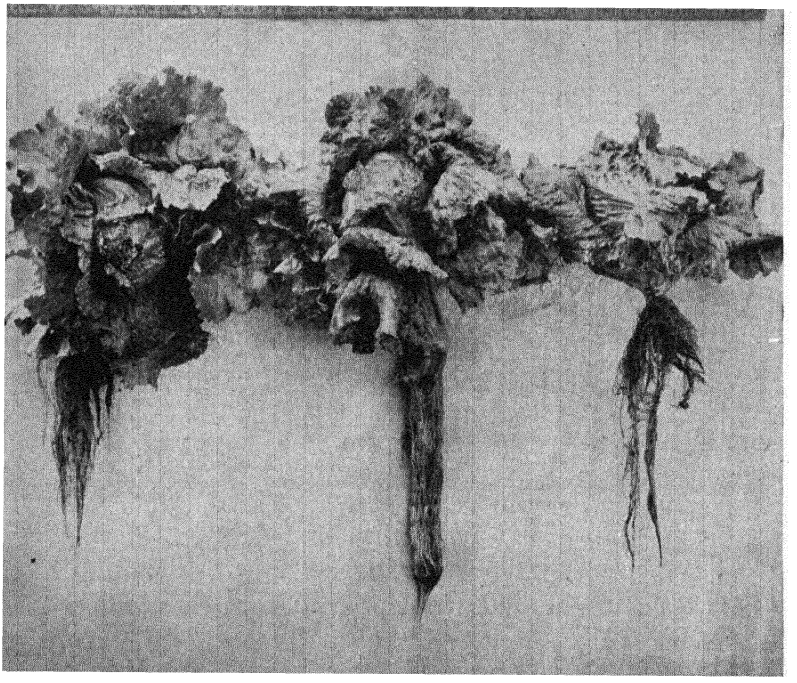

Fig. 34. Three heads of lettuce from the bed shown in figure 33. Note the pencil of roots characteristic of plants grown by water culture.

are not closer together than one for every square foot. Closer spacing can be used for lettuce having smaller heads, and lettuce that does not head should be planted sufficiently close together to cause mild blanching, which makes the leaves tender.

To facilitate aeration and to dry out the seedbed, lower the solution in the basin after the lettuce heads begin to form.

Endive is a form of lettuce requiring practically the same cultural treatment as head lettuce.

Cabbage

More acreage is planted to cabbage every year than to any other leaf vegetable. It is comparable to the potato in its wide geographical distribution. Because cabbage grows rapidly, it is well adapted to regions with short summers. It can withstand rather heavy frosts and thus can be both an early spring and a late fall crop. Where the ground does not freeze it can even be planted as a winter crop. The thickness of its leaves give it the ability to resist injury from intense sunlight, yet it can also be grown successfully in regions of limited sunlight. Cabbage is also at home in regions with bright days and cool nights.

Experiments have shown that cabbage needs certain substances which are produced by decomposing organic matter. If possible, therefore, use litter which has already been in use for several years. Or, if such material is not available and fresh litter must be used, cover it with a layer of soil a half inch or more deep. The seedbed should be cool, moist, and well aerated.

In planting, scoop a hollow out of the seedbed and insert the cabbage seedling. Unless the litter is already well decomposed, pack a handful or two of soil around the root crown. Keep the seedbed moist until the new roots have developed. You can insert the roots already attached to the seedling into the solution, but be careful not to immerse any part of the root crown. The cabbage plants will develop an abundance of fine, lateral roots which will later enter the solution. These roots are very sensitive to aeration conditions.

Cauliflower, broccoli, collard, and kale can be grown by the same methods described above for cabbage.

Parsley, Spinach, and Chard

These three are probably the most important of the vegetables whose mineral compositions can be altered by manipulation of the nutrient solution. Plants which grow either very rapidly or very slowly do not lend themselves to this type of

treatment. In the first case the gain in weight counteracts the increase in absorption of nutrients. In the other, changes in absorption are limited by lack of growth. But spinach, chard, and parsley with their moderate growth and moderate light requirements can be subjected to the maximum in composition-altering treatments without adversely affecting yield or quality of the product.

The three can be grown by the same cultural methods as are employed with lettuce. However, they can withstand colder weather and will grow under poorer light conditions. They are also less liable to suffer from poor aeration.

CHAPTER TWELVE

Seed Vegetables

THE PRINCIPAL crops grown for their seed, either green or ripe, are peas, corn, and beans. When grown in the garden for their green seed, they are known as "seed vegetables" and include string beans, green peas, and sweet corn. Peas are native to a colder climate than either of the other two. However, by making the proper selection of the many different varieties available, you can grow the three crops side by side. Their high food value, great productivity, and wide adaptation gives these plants an important place in any project designed to provide a maximum of food from a small planting area.

The fact that these plants adapt themselves to a wide variety of climatic conditions should not be taken as license for indiscriminate planting of any and every variety in any and every climate. Certain sections are always more favorable than others for the production of particular varieties. For example, the region around Ventura in California is ideal for Lima beans because of the cooling influence of the nearby Pacific Ocean on a region which is naturally warm. Other localities with special virtues for the production of certain seed-vegetable varieties are the Upper Mississippi Valley for sweet corn, Michigan for Navy beans, and Yolo County in California for the red-eye bean, which needs hot weather. As you might readily guess, such unique soil and climate combinations as exist for certain varieties in the localities named have given the clue to the sort of conditions which should be reproduced in hydroponics.

Few crops require less care in selection of seedbed materials than do the seed vegetables. They do not need as fine a litter as vegetables with small seed. An inch-deep layer of coarse litter topped with some fine material to retain moisture will meet their needs. The depth of planting, whether one or three inches, makes little difference in loose litter, although sprouting beans and peas may be lifted out of the seedbed by their blunt roots if planted quite shallowly. To protect against this contingency you can weight the litter with a thin layer of soil. Or you may even dispense with the fine litter and use soil instead. In general, two- to four-inch seedbed of coarse litter should prove satisfactory. The coarse litter will prevent the seedbed from holding excess moisture. At the same time the deeper bed will provide better anchorage for tall plants. You can add litter to the seedbed as the plants grow. The seedbed may even be used as a place for disposal of lawn clippings or vegetable refuse, thus adding to the available stock of seedbed material.

Sowing Different Varieties

Low-statured varieties of peas and beans, such as dwarf peas and bush beans, may be sown at a rate of one plant to every twenty-five to thirty-six square inches—either broadcast or planted in rows.

The tall or climbing varieties of peas and beans should be sown in rows so that they can be supported by a trellis. You should have one or two bean plants and two or three pea plants to every square foot. The rows should be a foot or more apart. A popular climbing bean that has done well is Kentucky Wonder. It makes a greater spread of foliage than do peas and consequently can be planted farther apart.

Low varieties of sweet corn may be planted at a rate of one plant to every hundred square inches. Tall varieties should be spaced one plant to every square foot or more. Seed may be sown broadcast or in rows from one to three feet apart. Wide rows, with close planting in the row, should be used only in basins large enough for a sufficient number of plants to insure pollination.

The distributions for planting given above for tall plants are much closer than is customary for these crops in soil. They may prove too close in some cases. Consequently, you must take an experimental view of the matter. Aim to obtain the closest stand possible without curtailing the supply of light which is essential to high yields. Because the litter seedbed cannot provide the support which is natural in soil, make the stand close enough so that rigid plants like corn will give each other mutual support. It is wise to select your varieties on the basis of this question of mutual support, particularly in localities where high winds are common. Thus, you should choose your corn on the basis of the least height required to make a good ear. Similarly, with climbing beans and peas, keep them as low as possible without interfering with production.

Wind must also be considered in its relationship to the pollination of corn. The pollen, a very fine dust which forms in the tassel of the plant, should fall on the silks of the newly developed ears and fertilize them. Heavy winds may blow this dust away and prevent it from falling on the silks, with the result that the plant has completely sterile ears on the windward side, unless you hand-pollinate the ears. This is done by breaking off a sprig of new tassel and shaking it over the silks of the ears. For the best pollination, the ears of one plant should be pollinated with the tassel from another.

Beans and peas are not dependent upon wind-carried pollen for their pollination, and thus the location of their rows has no effect on fertilization.

Beans and corn commonly appear above the litter about eight days after planting when temperatures inside the seedbed range from 70 to 80 degrees Fahrenheit. They can stand higher temperature, which will hasten germination. In some regions these crops are all planted when the seedbed temperature is about 60 degrees Fahrenheit. Weather cooler than this is unfavorable, but even so it is wise to plant these crops as early as possible in regions where summers are short and frosts early. Even a light frost will injure them, though corn can recover if the damage is only moderate. Beans and corn should be planted sometime during the three months of April, May, and June,

in regions with cold winters. High-yielding late varieties of string beans and corn require from 100 to 120 days to come into full production. In regions where the first frost comes in early autumn, therefore, these varieties should be planted before June.

Peas are more frost-resistant than corn and beans. Consequently, they can be planted earlier in spring and, where winters are mild, are even planted in late fall. In regions with cold winters, March and April are good months for planting. However, peas should not be planted when the weather can be expected to remain cold for some time to come. Continued cold leads to curtailed growth, premature flowering, and small yields.

Supports for climbing vines can be provided in several ways. Galvanized metal supports have been used, but in some cases have damaged the growing tips of the vines through zinc poisoning. Straight sticks have proved more serviceable than wire or fabric netting. Binder twine can be dropped from overhead cables or boards and fastened to the wire netting of the seedbed. The overhead supports can be attached to posts set in the ground at the ends of the basins.

Nutritional Needs

In supplying the nutritional needs of the seed vegetables, the basic formula may be used in essentially the same manner and quantities as were described for potatoes and tomatoes. The amount of food recommended for the potato may be taken as the maximum amount that any garden vegetable can use efficiently. It is probable that more economical use of nutrients will be obtained if the basic formula is modified to contain more nitrogen and comparatively less potassium. This statement is based on observations of the natural composition and vegetative growth of these high calcium and nitrogen plants, and not on experimental data.

Should you wish to test the accuracy of the recommendation for nutrition of these plants, you might use the following formulas:

1. The basic formula plus 20 per cent addition of calcium nitrate—$Ca(NO_3)_2$—so that the potassium-nitrogen ratio is 10 to 16 and the potassium-calcium ratio is 10 to 4.

2. The above formula plus 10 per cent increase in Epsom salt content—$MgSO_4$.

3. The basic formula plus 16 per cent of its weight in ammonium sulfate—$(NH_4)_2SO_4$—and 10 per cent of its weight in ammonium nitrate—NH_4NO_3. This gives a potassium-nitrogen ratio of 10 to 16, and retains the basic potassium-calcium ratio. These first three formulas are constructed on the theory that an increase in calcium intake would also mean an increase in absorption of nitrogen with a beneficial effect on yield.

Doubling the amount of chemicals named in the formulas may be still more beneficial if you correct the greater change in reaction that can occur in nutrient solutions where the nitrogen content is much greater than potassium.

It is improbable that the yield of ear corn would be affected by use of these formulas, although the plants might show more luxuriant foliage.

These seed vegetables produce lateral roots. Development of these can be encouraged by keeping the seedbed moist and scattering nutrients on top of it when the plants are a few inches high. Corn produces the largest lateral and vertical root development of the three species. Its roots enter the solution readily, unless a very great distance exists between the liquid and the litter seedbed. Practically all varieties of the three crops will readily establish themselves in the solution if their seed is planted in the litter about one inch above the wire netting.

The warm, bright sunshine which is ideal for corn and beans at the same time makes it relatively difficult to supply these plants with the proper amounts of iron. Weekly additions of this element to the solution will probably be necessary in many regions. When shallow seedbeds are used, even these additions may prove inadequate. On the other hand, a seedbed topped with soil may retain enough available iron to supply the complete needs of the plants without further additions.

Aeration

Aeration of seed vegetables is facilitated by use of coarse litter in the seedbed and the provision of an ample air space between solution and litter. Roots of corn and the vigorous varieties of beans and peas will easily cross an air space one to two inches deep. After the roots have become established in the solution, this space may be increased to three or four inches, if needed.

Warm weather and rapid growth accentuate the need for proper aeration. They also cause more rapid transpiration of water from the leaf surfaces. Fresh water necessary to replenish the loss by transpiration will also bring in much-needed oxygen for absorption by the roots. Thus, transpiration facilitates aeration.

CHAPTER THIRTEEN

Perennial Vegetables and Berries

PERENNIALS are plants that continue growth on the same root stock year after year and thus need not be replanted at the beginning of each growing season. An important problem in their cultivation has to do with carrying them through a successful period of dormancy each year. Some species, such as rhubarb, naturally go into dormancy at the end of their growth period. In growing such crops you must provide conditions which will produce a root system containing large amounts of stored food to support the new growth in the spring. Other species having woody tissue, such as currants and raspberries, may continue to send forth new stalks and leaves all through the year if climate is favorable. These plants you must supply with sufficient nourishment to allow the accumulation of food reserves. Normally dormancy is imposed on the plants by the character of the season, and overfeeding is not likely. In some cases where weather has continued warm late into fall, too large applications of plant food have kept woody perennials green too long, so that they did not harden sufficiently to withstand winter cold. Dormancy is a rest period from which the crops awaken in spring with renewed vegetative vigor if they have a large store of material in the root crown, roots, and stem.

Some perennials exhibit a peculiar difference from annuals in that they ordinarily produce very few feeding roots in spring during the period when new vegetative shoots are forming. Asparagus is an example. This is not serious so far as immediate

growth of the vegetable shoots is concerned. The plants must, however, contain in their roots and root crowns the reserves of food necessary to produce these shoots. The drain upon the plants' resources in producing their crops must be made up. Consequently it is important that the production of new feeding roots be encouraged.

It is not yet known how perennials withstand cold winters in hydroponic culture. In nature all parts of shallow-rooted perennials freeze solid in winter. It is probable that perennial vegetables and berries can be grown by hydroponics wherever they are grown by agriculture, without additional shelter. However, should it become necessary, the seedbed could be bodily transported to shelter such as a basement, or covered with material to keep excessive cold out. Artificial heating of the solution outdoors during cold winter weather probably would not be advisable but could be used advantageously in spring for early production.

Asparagus, rhubarb, and artichoke (the western or burr variety) are the principal perennial vegetables grown in beds that continue to reproduce without replanting for several years. New planting is not done until the crop begins to decline. In California, for example, asparagus does not decline in production until about eight years after planting. In other localities the average span of satisfactory production may be either longer or shorter. Approximately four years are required to bring asparagus into full productivity, although harvests can be taken before that time has elapsed. Good production is obtained in rhubarb and artichoke fields in the second year after planting.

These perennials require a deeper seedbed than do any of the other garden vegetables. Make your seedbed frame a strong one, using no boards less than six inches in width.

Asparagus should be started from seed. Scatter it on top of a layer of litter two or three inches deep, then cover it with another layer of the same depth. Most of the seed will germinate within two or three weeks, if presoaked for about a day.

During the first year asparagus is cared for in the same way as annuals. Plant food should be supplied to both the seedbed and the water. If possible, establish your stand during the first

year. Unfortunately, there are no available experimental data on the correct density of the stand, which should be established the first year. You might thin to nine plants per square foot for the first year, then wait until the second year to determine how dense the stand will be. The sprouts will not develop to full size until the beginning of the third year after planting.

The basic formula has given good results but conclusive data on the nutrition of perennial plants must await further experimentation, which must be continuous for a number of years

For rhubarb and artichoke, use a seedbed eight or ten inches deep. Planting stock is prepared in the same way as in agriculture. A large dormant plant is cut up into pieces, and the pieces are used for seed. The seed pieces are placed in firm litter, next to the wire netting, and about eighteen inches apart The root crowns will produce long, fine roots which penetrate the nutrient solution. The root systems of these two plants do not change so much in structure under hydroponic conditions as does the root system of asparagus.

In growing artichokes, it is well to remember that this plant cannot stand the extremes in temperature and light conditions as well as can other crops. If grown in regions of severe winters, it must be protected from frosts. It should be shaded in the summer to avoid heat injury.

Berries

Berries, though they are perennials, do not harbor the sizable food reserves that are characteristic of artichokes, rhubarb, and asparagus. Therefore, they are not independent of outside food sources during the fruiting or cropping season and must be provided with mineral nourishment just as are the annuals beginning from seed. Feeding roots are produced freely by these plants, whose nutrition is handled in much the same way as that of annual plants which produce large mats of fibrous roots.

Nevertheless, berries, despite their resemblance in some ways to the annuals, retain the perennials' ability to carry over into the next season the effects of deficiency in nutrients during a

preceding one. Good production is dependent upon the condition of the plants when growth ceases for the year. For example, if strawberry plants show an iron deficiency in the fall, the new leaves produced in the spring will also show the symptoms. The first fruit of the season will be small and deformed. This condition will continue until the plant has absorbed enough iron to care for the deficiency.

Strawberry planting stock consists of new plants produced from runners, the long stems which take root and become independent of the parent plant. New raspberry and currant plants are produced from suckers, which are new shoots that have rooted. Once berry plants have become well established, new planting stock is constantly being produced. By judicious selection of new plants and by pruning the old and excess growth you can keep the stock strong. When planting strawberries, or any of the woody perennials, insert the roots through the wire netting into the solution. If large plants are being used, the netting should have a 2-inch or 3-inch mesh. Keep the solution up within an inch of the netting. New roots will form from the old ones and also from the root crown. Within a few months the plants will have their full root size. In the case of strawberries, the production of new plants by runners keeps down the root development of the main plant. On the other hand, the production of new shoots by the main plants of raspberries and currants greatly increases the root system. This can become so large that thinning of both stalks and roots will be necessary.

Strawberries have been grown with the roots in solid ice for about two weeks during winter, without any apparent injury to the crop the next spring. Experiments with berry crops have brought out the following features:

1. Strawberries (the fruit) should rest on a dry surface to prevent decay. Rice hulls make an ideal top covering for the strawberry seedbed.

2. The interior of the seedbed should be sufficiently moist so that runners will take root.

3. Berry crops show iron deficiencies more quickly than do

perennial vegetables, but also recover more rapidly under corrective measures.

4. Hydroponic strawberries require protection from excessive temperature that would not be necessary in agriculture.

5. The nutrition of berry crops closely resembles that of cereal grains.

CHAPTER FOURTEEN

Field Crops

WHEAT, barley, oats, rice, corn, cotton, peanuts, tobacco, sugar beets, and some tropical crops—papaya, banana, and sugar cane—have been grown by hydroponics but not on a commercial scale. The high chemical cost for cereals, and the very deep seedbed required by sugar beets, prevent their cultivation in competition with agriculture at the present time. Nevertheless, the experiments in which the field crops were grown revealed some facts of great usefulness in growing other crops.

Basis for Stand

Experiments arranged to learn how closely crops can be planted showed that both size and age of the plants determine how much space each must occupy in order to obtain ample sunlight. A comparatively larger space is needed for the small, young plant than for the more mature plant which obviously occupies more room. The stand for cereals which produces the largest yields is one stalk for about every four square inches when the grain is ripe. The young plants require two or three times that area.

Size and age are influenced by extremely variable factors. Therefore, the rate of seeding which will be most advantageous for each crop cannot be prescribed for all regions and conditions. Particularly is this so with plants that tiller, as do all cereal grains, and with those, like tomatoes and other garden

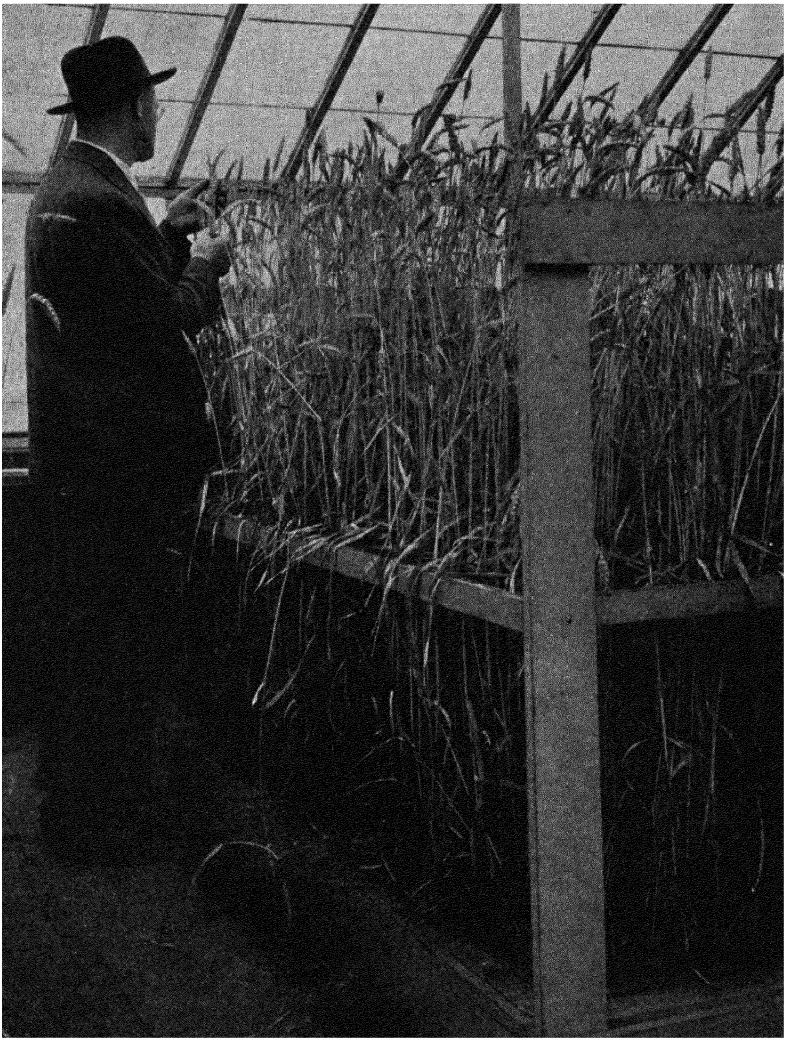

Fig. 35. Wheat grown in nutrient solutions to study the "influence of mineral nutrition on the composition and quality of grain for flour and bread."

vegetables and flowers, that also produce new shoots constantly. Plants that do not produce new shoots (like cotton) and those which are not allowed to do so (like banana) can be planted wholly according to the space they will occupy when mature. Low starch and sugar root crops, like carrots and red beets, can be spaced according to the area the storage root will occupy. Sugar beets cannot be crowded to a like degree, as crowding

Fig. 36. Peanuts—an interesting crop for experimenting in warm climates.

curtails sugar production by restricting leaves and by hastening the maturity of the plants. Tall tropical crops, like papaya, banana, and sugar cane, will probably adjust their growth to the space available without impairment of productivity.

The experiments showed that none of the small-grain cereals—wheat, barley, rice, and so on—can be planted closer than in agriculture, and therefore hydroponics cannot outyield agriculture. Cotton, corn, peanuts, and tobacco can be planted closer than is customary in soil, with corresponding implications of greater yields. The stand of sugar beet and sugar cane cannot be increased above that of agriculture, as light is the

limit... Papaya and banana apparently can stand closer together in hydroponic culture than in agriculture.

Formulas to Change Composition

The popular belief that all plants require different chemical formulas has also been disproved by growing them in the same solution. All the plants mentioned in this book have

Fig. 37. Papaya requires a deep seedbed. Small varieties should be chosen for hydroponics.

been grown from the same basic formula. (For information on relationship of plant composition to mineral food requirement, read the section on Multiple Cropping, page 261.) The formulas used in experiments designed to obtain different plant compositions showed (1) that the nutrients absorbed by the plants during their early growth stage determine their ultimate growth; (2) that the nutrients taken in during the latter growth stage influence the plant's composition because they are additions to the minimum quantity the crop must have; (3) that if the nutrients have been supplied in the proper quanti-

ties and combinations during the early growth stage, the plants can withstand unfavorable conditions later.

Evidence was also obtained concerning this important question: How much can the basic formula be altered without harm to the plants? It was found that:

1. Doubling the amount of calcium nitrate, treble super phosphate, and Epsom salts, singly or collectively, has no noticeable effect so long as the basins are drained occasionally to prevent accumulation of an excess of these materials or their residues.

2. Doubling the amount of potassium nitrate curtails growth, although fair development can be expected.

3. Doubling the amount of acid is serious if pure water is used, but with water high in solutes it is beneficial.

4. Halving the amount of calcium nitrate would have no effect.

5. Halving the amount of treble super phosphate and Epsom salts slows up growth of the plants.

6. Halving the amount of potassium nitrate has no effect at first under ordinary conditions, but additions must be made frequently.

You can obtain some idea of the possibilities for further experiment on the influence of different chemicals on plants by growing them on the basic formula for about one half of their life span and then growing them to maturity on just one of the chemicals mentioned below. This was done with wheat. It showed how markedly formulas might be altered, some with good, and others with bad effects.

Ammonium nitrate—NH_4NO_3
" phosphate—$NH_4H_2PO_4$
" sulfate—$(NH_4)_2SO_4$
" chloride—NH_4Cl

Calcium nitrate—$Ca(NO_3)_2$
" phosphate—$CaHPO_4$
" sulfate—$CaSO_4$
" chloride—$Ca(Cl)_2$

Magnesium nitrate—$Mg(NO_3)_2$
" phosphate—$MgHPO_4$
" sulfate—$MgSO_4$
" chloride—$Mg(Cl)_2$

Potassium nitrate—KNO_3
" phosphate—KH_2PO_4
" sulfate—K_2SO_4
" choride—KCl

Sodium nitrate—$NaNo_3$
" phosphate—NaH_2PO_4
" sulfate—Na_2SO_4
" chloride—NaCl

You can try these chemicals with flowers and vegetables, adding them at the rate of one pound to each 125 gallons of water. Remember, however, to give the plants a good start before putting them on their curtailed rations.

Further points concerning wheat are discussed in Chapter XIX. Points brought out in the study of the other crops mentioned are these:

Barley. Plumpness and quality of the grain demands restriction of the supply of nitrogen in the solution during the latter growth stage. Barley of high malting value cannot be obtained when the plants have an overabundance of this element.

Rye. The composition of this cereal, both straw and grain, varies least in comparison with other field cereal crops when the formula is altered, probably owing to the comparatively small area of active leaf surface and the correspondingly small absorption.

Oats. This cereal varies markedly in composition with changes in the content of the solution.

Rice. Has lower plant food requirement and shows greater variation in yield with different formulas than do other cereal grains. Paddy rice does not pollinate in a dry atmosphere, does not absorb and utilize iron as readily as do other cereals, but may actually have higher iron content in straw and roots.

Cotton. Absence of minor elements, particularly boron and manganese, shows quickly in this crop. The fact that these deficiency symptoms show more quickly in broad, thin-leaved plants requiring warmth and much sunshine might indicate that the availability of these elements is influenced by light conditions.

Tobacco. Shows seasonal influence of light more quickly than do other rapidly growing crops. Seedlings planted in May grew eighteen feet high before flowering. Those planted in November flowered when six feet high.

Peanuts. Loose litter four inches deep proved ideal for development of the underground flower stems on which the peanuts developed. The flowers on the stems in the air did not

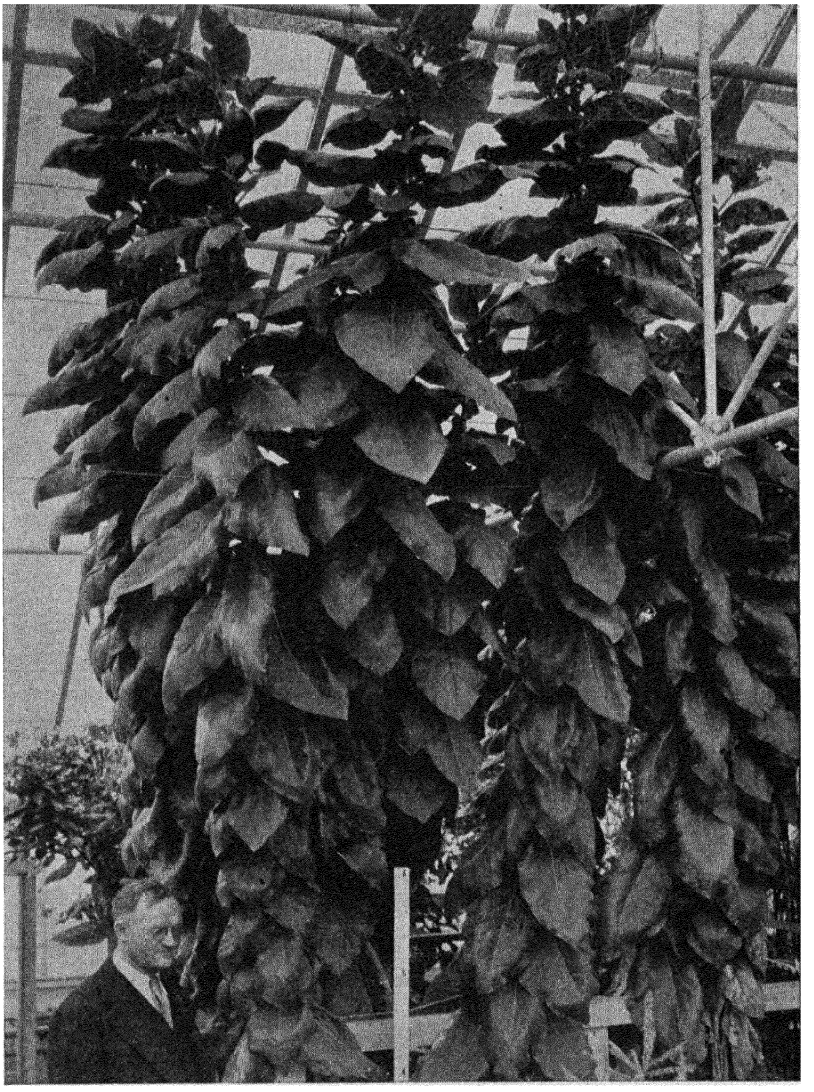

Fig. 38. Tobacco four months after seedlings were planted. Yield exceeds that of agriculture because of (1) closer planting, (2) taller plants, (3) uninjured leaves protected in greenhouse culture, (4) possibility of growing three crops per year under glass.

bury themselves in the litter as is usual in field culture. It is assumed the seedbed was too hot and too dry.

Papaya. Require an occasional complete renewal of the solution due to accumulations of toxic materials. Only crop of the great number grown in which the ordinary technique for supplying food and water in accordance with the plant's ability to absorb was inadequate without draining of the basin and a consequent waste of materials.

Sugar cane. Young rooted sprouts removed from the parent stalk failed to grow well when first placed in the solution. This shows the natural dependence of the young shoots of

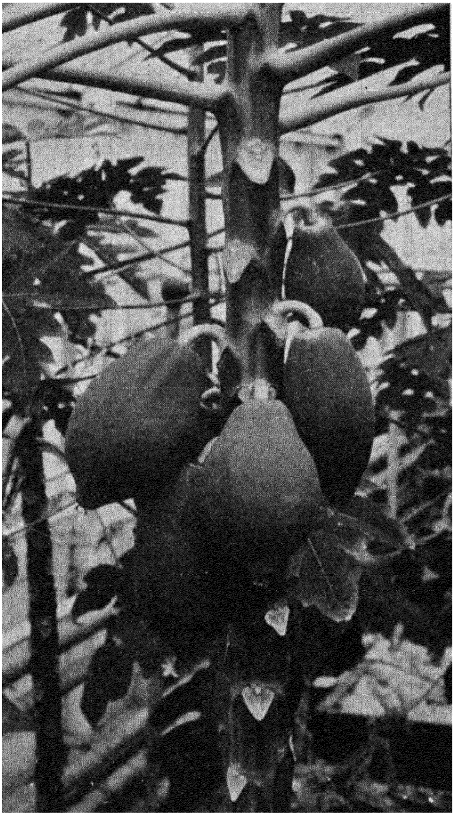

Fig. 39. Papaya in bearing. Male and female flowers are not on the same plant. In figure 37 there are too many male plants.

certain species upon organic food obtained from the mother stalk until they are large enough to manufacture their own.

Sugar beets. The sugar content of the beet is low while the plant is developing leaves but increases rapidly following the cessation of leaf growth. A period of vegetative dormancy should precede harvesting if high sugar content is to be obtained.

All annual crops show the importance of limiting the supply of nutrients in the culture media so that they become exhausted when the crop approaches maturity. This is in conformity with the pattern of nature—soils producing large yields become deficient in available nutrients when the crop approaches maturity. An ideal nutrient solution is one that provides plants with an abundance of nutrients during the early growth stage, when needed to produce large vegetative growth, and which is completely used before the plant matures, so that for the latter part of its growth period the plant grows in a nutrient-deficient medium.

CHAPTER FIFTEEN

Herbaceous Annual Flowers

FLORICULTURE is the most specialized branch of plant production. Flowers and decorative plants require more individual care than do field and vegetable crops. They include many more species and varieties, are grown under more diverse conditions, often away from their natural habitats, and are more widely distributed geographically. Nearly all failures in flower production result from inability of the grower to fit cultural techniques to climate requirements. The question of techniques cannot be treated in generalities. It must be discussed separately for each species. However, by studying those flowers which are grown most extensively you may obtain a comprehensive grasp of the subject. This will in turn enable you to master the more detailed technique essential to successful production of any specific flower.

Flowers have been used in water culture experiments since 1927. In fact, the rose was the first crop ever grown by hydroponics. It supplied some of the most important clues to cultural technique, particularly the fact that it must be centered around climatic rather than nutritional factors. The mineral nutrition of floral crops is no more specialized than that of vegetable and field plants. But many flowers are much more sensitive to vagaries of climate, and cultural technique must be adjusted to these changes.

The Production of Flowers

Another book will be required to deal with the details of growing the important floral species. These chapters will be limited to a general survey of the field in which hydroponics will operate as a flower-producing medium and some statements concerning the cultural technique to be used. The field for hydroponics may be divided into three sections: growth of

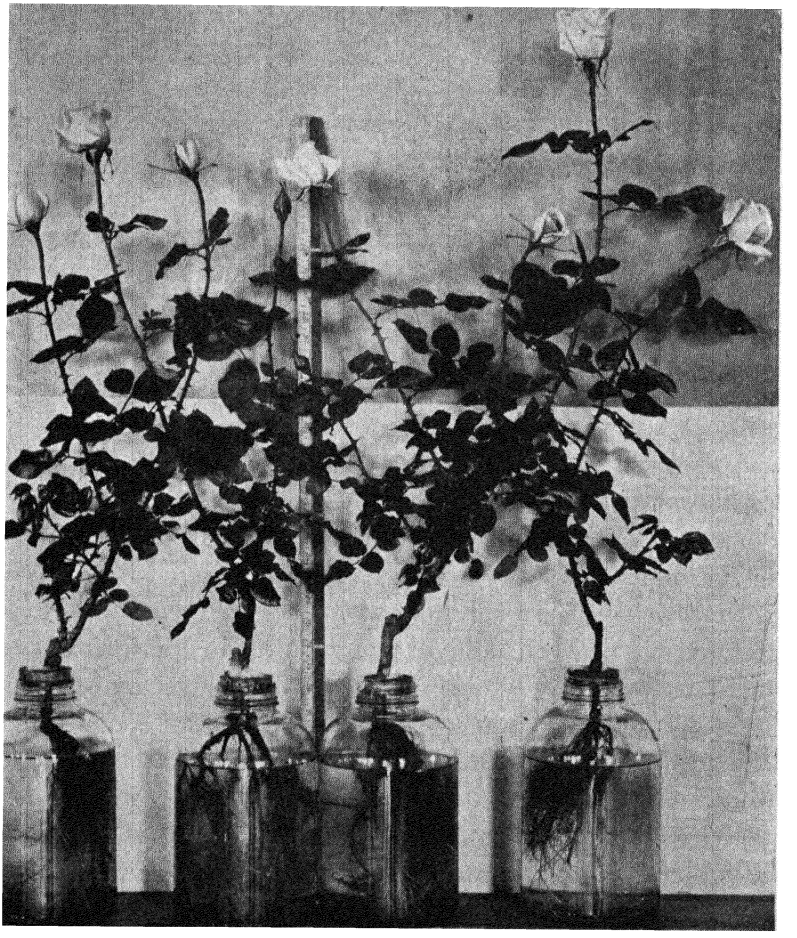

Fig. 40. The first roses grown by water culture, in 1927. Published in American Rose Annual, *1930.*

flowers in the home, in the garden, and in commercial plants.

Of the three you will find the first the most difficult. Plants which have low light requirements and are adapted to growth inside the house also have comparatively small root systems. Consequently, they are harder to handle under hydroponic conditions. However, many hardy perennials able to thrive in shade are not grown inside at present because of the cumbersome equipment required. Hydroponics will make it possible for you to grow them in much smaller containers. The development of cultural technique, selection, and breeding of floral crops for extensive decorative use in the home promises to become increasingly important. It is conceivable that in the future houses may be constructed with built-in attachments for growth of flowers.

House-grown plants are often less sensitive to nutritional factors than are those grown outside, and respond more slowly to applications of plant food. You must supply them with the best possible growing conditions from the very start. Probably, you will find it advantageous to grow some plants outside in special soil or sand, then transplant them during blooming to basins inside the house. When they decline, they may again be removed to the outside basins. In this way a larger use of plants, rather than cut flowers, for home decoration may be encouraged.

Garden Flowers

Hydroponics should have a special appeal for the home gardener, for a large array of garden flowers can be grown by this method. Many of the most popular flowers are well adapted to growth in nutrient solutions and require little care once they are well established. The equipment for the hydroponic garden may be modified to suit the setting of home and surroundings, thus providing a luxuriant growth of flowers without appearing artificial. Plants with low light requirements may be grown in tanks placed at the bases of trees or in the shade of taller flowers. You might begin the season with species propagated from bulbs, such as daffodils or tulips; follow these with warm-weather flowers such as marigolds, asters,

zinnias, or gladioli, then with chrysanthemums for fall blooming.

Some of the choicest blooms are produced by wild flowers. At present too little is known of their cultural and climatic requirements to allow any prediction of their response to hydroponics. In time they may provide new and beautiful additions to many gardens.

Herbaceous Annuals

Among the herbaceous annuals we include those flowers, such as marigolds and asters, that are started each year from seed, and those, like chrysanthemums and carnations, that are planted

Fig. 41. Marigolds in an outdoor garden.

as green cuttings. The last two species are actually perennials but, since new plants are used each year, they will be considered as annuals so far as hydroponic production is concerned. There is no important difference between the nutrition and cultural technique of perennials and that of annuals except in regard to their effect on the plants' root systems. Since the annuals are started anew each year, you need not consider the effect of hydroponic conditions on root structure, a question of great importance, however, in the cultivation of perennials.

The importance of getting annuals off to a good start cannot be overemphasized, especially in the case of plants with small seed, such as begonias and snap-dragons, which naturally grow slowly until they have attained considerable size. Such species are sensitive to variations in temperature and moisture supply. They should be planted early in flats of select soil or sand covered with glass to prevent drying. Very shallow planting is recommended so that the seeds can obtain oxygen. From the germinating bed they are transplanted to larger flats. Then, when the seedlings are large enough to handle easily, they are transplanted to the hydroponic basin.

All garden flowers are easily transplanted from soil flats to the litter seedbed. This method is particularly practical in regions where summers are short. In such localities the plants can be started early and transplanted when the weather becomes favorable.

If you intend to grow flowers where the favorable growing season is a long one, you can sow the seed directly into the litter seedbed. There is no essential difference between the methods of sowing flower seed and vegetable seed.

Starting from Green Cuttings

Green cuttings start best in coarse sand. They do not start well in nutrient solution, and consequently should be rooted before they are set into the litter seedbed.

Small seedlings, started from seed or rooted as green cuttings and then transplanted to larger flats of soil or sand, can be treated with nutrients to hasten their growth, thus shortening

the time required to get them ready for the hydroponicum. Readiness for transplanting is a state hard to describe. It is more a matter of firmness of the plant tissue than of age or size. Essentially, it is the stage at which the plants produce new roots readily. In the common herbaceous annuals, this stage is reached when the plants are between three and six inches in height. In transplanting follow the directions given in Chapter VIII, on tomatoes.

Effect of Cold and Heat

In selecting the time for planting or transplanting annuals in basins out of doors you must consider the plant's resistance to heat and cold. Of those seedlings grown successfully by hydroponics the ones that can be characterized as cool-weather plants for germinating seed are daisy, calendula, stock, sweet pea, delphinium, snap-dragon, marigold, pansy, chrysanthemum, and nasturtium. These will grow at seedbed temperatures as low as 60 degrees Fahrenheit. However, temperatures running about ten degrees higher than this are more favorable for most of them.

Annuals suited for warm weather and which have been grown successfully by hydroponics include zinnia, marigold, begonia, hollyhock, aster, scabiosa, canna, coreopsis, and verbena. Flowers injured by temperatures above 80 degrees Fahrenheit include begonia, pansy, and carnation.

High temperatures are usually associated with intense sunlight. Few flowers fail to show harmful effects when subjected to these conditions. Of the flowers mentioned, begonia has the lowest and zinnia the highest tolerance for light. When in bloom, all the plants react favorably to shading with cheese cloth or light muslin on bright days. Knowing the effect of sunlight on the flowers, you will naturally place your basins accordingly. With the exception of those having low light requirements, all the annual flowers can be grown satisfactorily under the ordinary exposure to sunlight found in gardens.

Plants grown by hydroponics reflect changes in temperature and light exposure more quickly than do those cultivated in

soil. Some are so damaged by a few hours' exposure to intense sun that they remain stunted for life. The data available on plant tolerance are derived chiefly from controlled experiments in the laboratory. Consequently, the decisive influence of erratic factors, such as the excessive short-time heat due to reflection of light, often escapes notice.

Transplanting

When transplanting from soil flats to the litter seedbed, set the seedlings with attached soil next to the wire netting. Their roots need not be in the solution. Unless the seedlings are very young, their soil-formed roots will die when immersed in the solution and new ones will form in their place. You must protect the plants from high temperatures and intense sunlight, as well as from excess moisture, until new roots have been produced.

Species which have a restricted root crown and whose new roots are produced from a small section of the plant should be set next to the wire netting. Those whose roots strike out from large areas of the plant may have some of their roots placed directly into the solution upon transplanting. The daisy, whose new roots can rise from the axil of the leaves, is an example of the latter type.

Classification of Root Systems

In preparing the seedbed for any one species, you must consider its root system. Root systems of herbaceous annuals can be divided according to size into four groups:

1. Pansies and begonias have the smallest. These plants have a mass of fine roots about three inches long, and require a shallow seedbed. For pansies the surface of the bed must be kept dry and its interior moist. The nature of the seedbed litter should be such that it will not pack down hard. It could be made from wooden chips mixed with decomposed litter and covered over with a half-inch layer of rice hulls or other material of low water-holding capacity.

2. The next largest root systems are those of snap-dragons, asters, verbenas, nasturtiums, and carnations. For these plants make the seedbed about three inches deep.

3. Marigolds, coreopsis, scabiosa, zinnia, stock, chrysanthemums, and daisies are adapted to both shallow and deep seedbeds.

4. Hollyhocks, delphinium, and sweet peas produce strong roots, growing both laterally and vertically. A seedbed four to six inches deep, of coarse litter weighted down with soil, will prove satisfactory.

Most herbaceous annuals produce an abundance of lateral roots which, once established in the seedbed, become the means by which many of the difficulties encountered in growing these plants by the laboratory method are eliminated.

In some cases the best results are obtained by growing just one species alone. In others it may be best to mix the species so that tall plants may give shade and protection to those of lower temperature and light tolerance.

The purpose of inducing large root growth in the seedbed is (1) to provide anchorage for the plants, (2) to facilitate and simplify aeration, and (3) to simplify the task of providing plant food by making it possible to add the chemicals directly to the seedbed.

Marigolds

Space is not available for a complete discussion of each species of herbaceous annual. Fortunately, one of the group, the marigold, can be described, and the points brought out in its discussion apply more or less to all other flowers in this group. However, you must realize that each species has its own peculiar characteristics. If you wish to realize the greatest potentialities of hydroponics and produce the finest flowers, you must take these characteristics into account. Of almost equal importance is the choice of the proper varieties for use in hydroponics. The difference between plants of the same species may be greater than that between species, themselves. The experiments with marigolds illustrate this point.

Marigolds are grown extensively both in home gardens and for the florist trade. There are two chief types: the dwarf or French, and the tall or African. Each has several different varieties. Some marigolds, while having the same type of flower as the dwarf, grow as tall as the African.

The plants are usually grown from seed sown in soil flats and then transplanted when they are several inches high. All marigolds have extensive root systems. The dwarf type, particularly, grows very long roots and is one of the most satisfactory flowers for hydroponics. It requires little care, since it is able to grow under a wide range of temperatures and chemical reactions in the solution. Often it can be left for an entire season without additions of chemicals, even of iron, after the original plant food has been provided. It is an ideal plant for those of you who are just beginning to use hydroponics.

In experiments four varieties—French, Harmony, African, and Guinea Gold—were grown under identical conditions. Harmony is a selection of the French type and Guinea Gold of the African. While the others thrived, Guinea Gold failed to grow well. It was soon found that the type of seedbed used was not suited to a plant of Guinea Gold's rooting properties. Its well-developed lateral and vertical roots enabled it to draw a large amount of water from the solution and hold it in the root mat. The fine litter used had a high water-holding capacity and allowed the moisture to accumulate under the plants. In time the root crowns began to rot. To remedy this, another seedbed was designed in which a two-inch layer of very coarse litter was first put down. The seedlings were placed upon this. Then the fine litter needed to give the seedbed the required water-holding capacity was added at spots removed from the stems of the plants. Their lateral roots were able to reach these sources of moisture, but at the same time the bed was kept dry immediately around the stems. Then the plants thrived.

So here we see again the importance of adapting cultural technique to the individual requirements of the plant grown. French, Harmony, and African marigolds grew well in a seedbed with fine material in the root zone and coarse litter on top.

Yet Guinea Gold, a plant of the African strain, needed a bed constructed in just the opposite way.

You may grow marigolds either in bottles or in basins. Seed may be sown directly in the seedbed, or it may be sprouted in soil and the seedlings transplanted to the basins when they are from three to four inches high. In transplanting from soil, take the seedling with earth attached and set it in a hollow scooped out of the litter. It should be planted deep so that it touches the wire netting. You need not insert its roots in the solution. The seedlings of the largest varieties should be about twenty inches apart to insure sturdy growth. If the seed is sown broadcast in the seedbed, the sprouts must be thinned out or transplanted until this spacing of plants is obtained.

When marigolds are to be grown in bottles, the seed must naturally be sprouted in soil or in a litter seedbed. In placing seedlings in the bottles, follow the laboratory method of passing them through cork stoppers and placing cotton in the necks of the containers.

Seedbeds from two to three inches deep are ideal for marigolds grown in basins. The litter may be weighted down by a layer of soil if coarse, open material is being used. You must keep the beds moist until the roots are well established in the solution. Up to this time the liquid must be kept up to within an inch of the seedbed but you may then allow it to recede about three inches. When it has reached this level, additional water should be added. But never let the solution remain in contact with the seedbed for any considerable length of time. In regions of heavy rainfall you will be wise in placing an overflow pipe in the basin to insure against such an occurrence.

Within three or four days after the plants have been set in the seedbed, scatter plant food on the litter. One pound of the basic chemical mixture should be added to every 25 square feet. If the climate is dry, you may sprinkle the bed to dissolve the nutrients and carry them down into the root zone. In about two weeks the roots will have established themselves in the solution. Then add food to the water at the rate of one ounce of the basic formula to every cubic foot. If you do not wish to

make tests for the food content of the solution, follow the nutritional procedure given for potatoes in Chapter IX. For plants grown in bottles, the original dose of nutrients will be at the same rate as in the basin—one-tenth per cent of the weight of the water.

CHAPTER SIXTEEN

Flowers from Bulbs, Corms, Tubers, and Rhizomes

SOME of the most popular garden flowers are grown from bulbs, corms, tubers, and rhizomes. These are buds enclosed in forms holding relatively large quantities of plant food upon which the flower may draw for nourishment during its development. In some species so much food is contained in these forms that the flower can develop to size without added mineral nutrients. However, none of these species will obtain the growth necessary for production of good seed stock unless some additional food is provided by outside sources. The amount required naturally varies over a rather large range.

Flowers grown from bulbs, which are embryo blooms enclosed in several layers of thickened leaf material, include daffodils, narcissi, tulips, and hyacinths. A corm is a bud in the base of the thickened stem of the flower where reserve food material is stored after maturity has been reached. Flowers grown from corms are gladioli, tritonia, and montbretia. A tuber is the enlarged, fleshy stem which develops underground and is attached to the main body of the plant by a smaller stem. The dahlia is grown from a tuber. A rhizome is an underground root-like stem that sends out leaves on its upper side and roots on its lower. It is more dependent upon the main plant than is the tuber but not so much so as the bulb or corm. The iris is grown from a rhizome.

The method by which a plant produces buds gives the clue to its dependence upon mineral nutrition. For example, under ideal conditions the bulbs of the daffodil contain more than 75 per cent of the weight of the plant after the leaves have dried. In other words, substantially all the food required to bring the daffodil to flower and to the size of the parent plant is contained in the bulb you plant. Nutrients must be provided for the daffodils to increase themselves by producing additional bulbs from the one planted, and to supply that which is lost if the flower is removed, or allowed to ripen, producing true seed.

Other plants require more mineral nutrition, as the seed stock contains comparatively less food material. When we investigate these plants we find that their seed stock comprises a relatively smaller percentage of the weight of the whole plant than does the daffodil bulb to the entire daffodil plant. Thus we get the principle that the degree of dependence of one of these flowers upon mineral nutrition is roughly directly related to the ratio of the weight of seedstock to the weight of the entire plant at maturiy.

Flowers from Bulbs

The rule in planting daffodils, narcissi, tulips, and hyacinths in soil is to place them two to four times as deep as the thickness of the bulb. The depth of planting in hydroponics depends largely upon the type of litter used and the season of planting. Bulbs are normally planted in fall or early winter in regions where the ground does not freeze. Cool weather is ideal for their cultivation. Hydroponics allows a longer planting season than does agriculture because it permits cultural technique to be adapted to climatic conditions.

It must be emphasized that bulbs differ from true seeds in that they reflect the influence of the weather conditions to which the parent plants were exposed. A true seed formed by union of male and female cells in the flower of the plant contains no vegetative tissue of its parents and reflects only heritable qualities.

Cut a daffodil bulb straight through from one side to the

other and inspect the embryo flower, which should be apparent at once. This is a miniature plant that has been exposed to last year's climate and carries some of the effect in the vegetative tissue of the bulb. If the embryo flower is not easily visible inside the bulb you may be sure that no flower will be produced that year.

Do not believe, however, that any failures of your bulbs to produce satisfactory flowers can be traced wholly to unfavorable conditions the year before. A bulb may be of good stock and still fail to give a good flower simply because unfavorable cultural technique or weather exposes it to the wrong kind of temperature and light conditions. The daffodils are the least affected of all bulbs and thus are well suited to a wide range of conditions. They can even be grown successfully indoors in window boxes under light conditions under which it would be much more difficult to grow tulips.

So far this discussion of bulbs has been limited to the large ones which flower without being supplied with additional nutrients. Small bulbs, such as the bulblets contained on gladiolus corms, cannot flower unless they first develop enough leaves to produce a stalk. They are immediately dependent upon outside sources for the food needed to make this development. They adjust their growth to the supply of food available. If this supply is small, they may require several seasons to grow to size. If it is ample, a full-size plant will develop, produce a flower, and reproduce itself in the form of a large corm in one season.

It is obvious that the importance of mineral nutrition and cultural technique varies in the cultivation of different bulb flowers. If a daffodil bulb is of good seed stock, you may expect the plant to produce a flower if it produces leaves. Tulip culture is a little more difficult. Flowers may not develop on tulip plants, even though the bulbs are sound and leaves are produced, because it is necessary for the plant to produce a stem. Whether the embryo flower and stem will develop depends upon light and temperature conditions. With light we also must consider the requisite amount of darkness. Daffodil bulbs will develop flowers without being covered. Tulips re-

quire covering to obtain darkness to get the stems started; they naturally get darkness when planted in the ground. The proper alternation of light and darkness also affects the character of flowers and some plants.

The gardener interested in growing flowers from Holland bulbs finds that his chief problem lies in getting flowers with long stems. On the other hand, the grower of planting stock

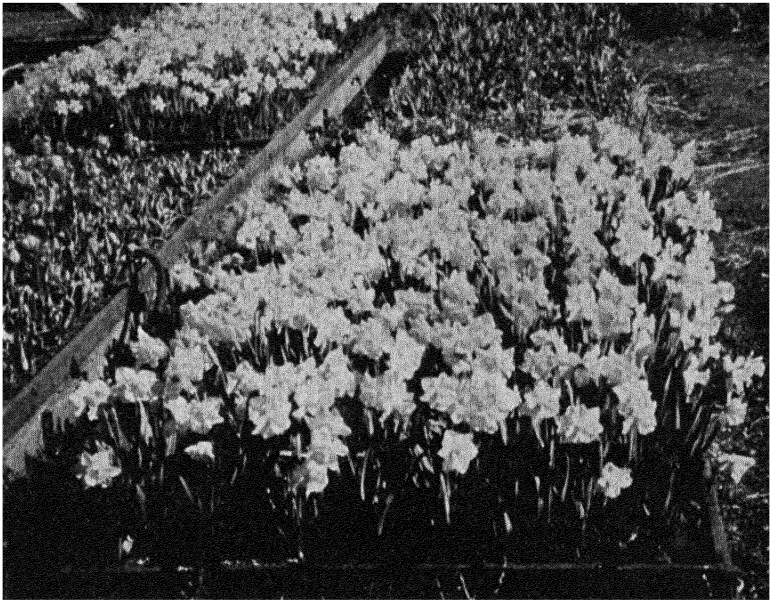

Fig. 42. Daffodils give a mass of color when planted closely.

strives for bulbs of large size. If you are interested in growing both flowers and bulbs by hydroponics, first select good stock. Some of the large daffodil bulbs are "two-nosed"; that is, they produce two or more flowers, as each bulb planted was actually a clump of smaller ones. Bulbs increase by division. A two-nosed bulb is one in which all the physiological preparation for production of two or more bulbs has been completed but the actual mechanical division has not yet taken place.

Planting bulbs deep keeps them cool and is conducive to production of large bulbs; planting them shallow exposes them

to high temperature, and is conducive to division and small bulbs.

Unfortunately, experimental data on the cultivation of Holland bulbs by hydroponics in regions with severe winters are not available. The directions given below are based on experiments carried out in California. But, since bulbs withstand cold, it is assumed they can be grown by hydroponics wherever

Fig. 43. A closer view of the daffodils shown in figure 42.

they are now grown without unnatural protection. Bulbs are usually planted in the fall, but in regions where the ground does not freeze during the winter months they can even be planted late in January. Fall planting is customary so that cool weather will allow the bulbs to become well rooted before they bloom. If this opportunity is not offered them, leaf growth exceeds root development, comparatively, and both leaf and root growth are shortened.

When planting bulbs, place them upright on a two-inch

layer of straw, or on a half-inch mat of excelsior, laid loosely on the wire netting over the basin. Then cover the bulbs with litter. They should be about a half inch above the netting after the seedbed has settled. Take special care that they remain upright. The seedbed should be at least four inches deep even after it has settled. This depth will keep the largest bulbs well covered. They will grow and produce flowers if only partly covered, but under these conditions they will be more exposed to variations in climate and their future quality may be impaired.

Under good hydroponic conditions, daffodils develop a large number of single-strand roots six to eight inches long. Tulips produce a large number of finer single-strand roots two to three inches long. Hyacinths stand between these types in size of roots.

The distance from each other at which bulbs are planted depends upon the effect you wish to achieve. They will grow well singly, or if you want a mass effect in a small flower bed, large tulip and daffodil bulbs may be planted from four to nine per square foot. From nine to sixteen of the small-size bulbs can be planted in the same area. Hyacinths should not be planted so closely.

You can fill the basin with water immediately after planting, or you can wait until the roots are started. In either case the seedbed should be moist. Although Holland bulbs withstand a greater variation in moisture content of bulbs without harmful effect than other plants, nevertheless, you should arrange the character of the litter and depth of planting in anticipation of the season. If wet, plant shallow and use litter with low water-holding capacity; if dry, plant deeper.

Solution temperatures ranging from 50 to 55 degrees Fahrenheit, and air temperatures between 50 and 70 degrees are favorable for starting bulbs. After the plants are well rooted, they can stand higher temperatures, but when the flower begins to form, the solution temperature should be kept low, 60 degrees if possible. The flowers will last longer.

Few plants require less care in the provision of plant food than do the bulbs. Chemicals may be provided entirely through

Fig. 44. A bed of tulips with stems about two feet tall.

the solution or entirely by application to the seedbed. In the latter case the chemicals can be washed down by sprinkling. There is no danger of injury to the bulbs by the chemicals. No experimental data on the amounts of food they need are available but, when nutrients are added to the seedbed, you may feel safe in using three pounds per twenty-five square feet. This amount will not be excessive, but probably much more than will be used. Apply the food one pound at a time, with the last application coming after the flower has been removed. Usually the iron contained in the formula will be sufficient, but if the bulbs are exposed to intense light they may show iron deficiency symptoms. These are easily recognizable as the entire leaves of the plants become light in color.

Holland bulbs offer an excellent opportunity for hydroponic experimentation. By changing the depth of litter used, in order to influence temperature, and by adding various quantities of the chemicals named in Chapter XIV, on field crops, to the solution, both before and after flowering of the bulbs, you may develop the combination of cultural and nutritional technique required to duplicate without soil the superior bulb stock grown in regions blessed with ideal soil-climate combinations. The basic formula has given good results, but it is very possible that a formula containing from five to ten times as much nitrogen as potassium might prove beneficial. The formula should then contain more phosphorus.

You should not allow seed in the flower to ripen if you wish to develop good bulbs for the next season. Unless the plant has large foliage, do not remove any of the leaves while cutting the flower. You will also be wise in adding more litter to the seedbed with the approach of warm weather in order to keep the bulbs cool and moist until fully mature. If it is necessary to remove them before they are fully mature, you can dig a ditch and place the bulbs in it, taking care to keep them well covered and to keep the ground sufficiently moist to prevent the plants from drying out.

Flowers from Corms

Corms are planted in the same way as bulbs. Gladiolus is the most popular flower of this group. It grows tall and its roots do not provide it with very good anchorage. It starts with thick, stiff roots that grow downward. Later small roots grow out from these large ones. Practically no lateral roots are enmeshed in the seedbed to anchor the plant. For plants growing about a foot tall, no support will be needed to prevent lodging. For those that grow several feet tall, support will be needed.

A simple method of providing support to such plants is by placing a screen of two- or three-inch mesh wire over the seedbed. As the plants grow up through this screen, raise it accordingly.

Plant food may be supplied in the same way and in the same quantities as recommended for bulbs. Gladioli show iron deficiency symptoms more quickly than do Holland bulbs. Add iron when these symptoms appear.

In wet regions an air space three inches wide between seedbed and solution will be sufficient for aeration of gladioli. In dry regions this space should not be more than two inches deep.

In regions of mild winters, such as Florida and California, gladioli can be planted at any time during the year. Wherever severe winters prevail, planting begins in March. Early varieties of this plant require about seventy-five days to produce a flower. Thus, June is the latest they can be planted for flower production in regions of short summers. June is too late to allow the new corms to form before the flower spike appears, as most of their growth is made after flowering.

As a rule, flowers grown from corms are better adapted to dry climates than are the Holland bulbs. By protecting them from excessive heat and sunlight when the flowers begin to form, you will obtain better-keeping blooms.

The influence of light on flowering of gladioli was shown in the failure of an early variety to bloom, but a late variety (see

figure 45) planted at the same time in December bloomed well, as flowering came when days were longer. When these varieties were planted together in spring, both produced good flowers.

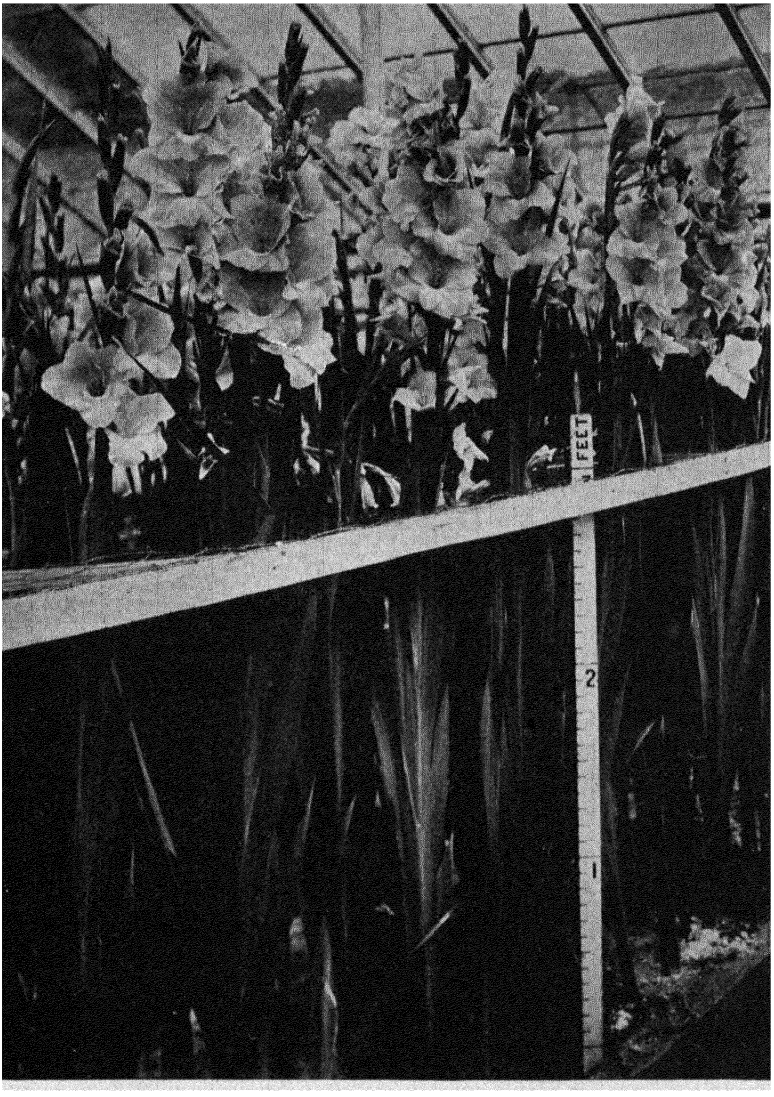

Fig. 45. Gladioli thrive in hydroponics, both in the greenhouse and out of doors. These were grown in winter as a forcing crop.

Rhizomes

Cannas, and German and Dutch iris are produced from rhizomes. They have been grown successfully by hydroponics. They are planted in the same way as bulbs.

The canna was originally a tropical plant and so does not withstand cold weather. You may find it wise to remove it from the hydroponicum and store the roots during the winter. Cannas are adapted to northern gardens because of their rapid growth. Few plants equal them in adaptation to both wet and dry conditions of the seedbed, or in the range of temperature at which they grow, or in the readiness with which they produce new seed stocks. It is a good experimental plant for the beginner.

The iris is a very large family of flowers, and species can be found adapted to very diverse conditions. The garden varieties produce rhizomes on or near the surface of the ground, a feature which suggests their need of air. In wet regions the iris is planted near the surface of the litter bed, in coarse material with low water-holding capacity. In dry regions it is planted three to four inches deep. Although the rhizomes are more susceptible to decay than are Holland bulbs, they are less damaged by exposure to high temperature. While iris is a shallow-rooted crop, its roots do not develop extensively in the seedbed. Nutrients should be added both to the seedbed and to the basin. The basic formula has given good results.

Tubers

The most important flower propagated from tubers is the dahlia. It is an import from the high plains of Mexico. Originally it was purely an autumn flower, but now it has been developed so that it may also be grown to bloom in the summer. The plant is very susceptible to frost and heat, although even in regions of short summers it has been grown successfully because of the rapidity with which it develops. In frost-free regions it can be grown all year. However, it is not strictly a perennial, and responds more satisfactorily to the same cultural

technique given to annuals. Warm days and cool nights provide the most favorable climatic environment for dahlias. They have no equal among garden flowers in rapidity of growth, profusion of bloom, and variety of color. Varieties have now been developed which are suitable for commercial trade as cut flowers.

Dahlias, because of their rapid growth and large system of absorbing roots, are particularly well adapted to hydroponics. They overcome difficulties of iron deficiency, aeration, and temperature that seriously injure less vigorous plants. Their root systems quickly absorb and use the iron provided before it can become unavailable. The profuse foliage shelters roots and stalks from the sun and high temperatures. Finally, the fact that the roots are long permits a wide air space between seedbed

Fig. 46. Dahlias grow to good height. Pompom dahlias are in the foreground.

and solution, thus facilitating aeration without lowering the absorbing capacity for water. It is this last factor which makes it possible to grow dahlias by hydroponics in regions where they cannot be grown in soil. In constructing the seedbed for dahlias, the materials need not be very fine, nor do the equipment and cultural technique have to be as refined as in the case of many other flowers.

Soil-grown dahlias are comparatively free from disease and the different varieties differ in their requirements only slightly. Nevertheless, in hydroponics it will be well to select seed stock carefully. It is possible that soilless conditions will tend to accentuate susceptibility to mildew and lodging, by overstimulation of growth in varieties prone to weakness in these characteristics.

Choice of dahlia varieties for hydroponics should be based on three considerations: (1) resistance to mildew, (2) ability to anchor strongly in seedbed materials, (3) strength and form of stalk and leaves.

Litter seedbeds do not offer so secure an anchorage for the flowers as does the soil. Consequently, to prevent lodging in the seedbed, choose short varieties with spreading branches rather than the tall tpyes. This does not mean that the tall varieties cannot be grown successfully, but they often require mechanical support.

Dahlias are usually propagated from tubers and rooted cuttings. Those propagated from tubers run true to the parent type, which is often not the case with dahlias grown from seed. Nevertheless, choice dahlias can be grown from seed, and some of the new varieties produced each year are seedlings.

Whether the seeding should be done directly in the litter or whether the seed and tuber should be pre-sprouted depends entirely upon the season. Six to eight weeks may be gained by pre-sprouting inside before outside planting is possible. Pre-sprouting is especially valuable in regions where frost-free weather prevails only about four months out of the year. It can be done in the customary way in soil flats.

The first roots in tubers appear on the end opposite the bud. They are primarily water-absorbing organs. The food-absorb-

ing roots of dahlias are those that grow from the base of the new shoot. They usually start to form a month or more after the shoot has appeared. Before this time the plant is subsisting on the food contained in the tuber. Once new absorbing roots are formed and have started to do their work, the plants turn a lighter green and grow rapidly.

Dahlias grow well alone but the best effect is gained when a number of varieties are grown together. A basin three feet wide will accommodate two rows of plants to good effect. The basins should be at least six inches deep, since dahlias need a large amount of water.

Tuberous Begonia

By strict rule of classification, the tuberous begonia should not come in a class with the dahlia as the representative of tubers. It does not produce a root system like the common tuber crops and therefore the cultural technique is different. Although this begonia is extensively propagated from seed, the average gardener uses bulbs. The production of these plants is limited by climatic factors more than are most floral crops, thus requiring a more specialized cultural technique. The plants cannot withstand hot or cold weather, but if protected from frost and bright sunshine, choice begonias will bloom from four to six months of the year under ideal conditions.

Figure 47 shows begonias grown hydroponically. The basins are 25 feet long by thirty inches wide and four inches deep. The seedbed is four inches deep and consists of litter with a thin top of fine soil. On the first of April each basin was planted with twenty-four large bulbs, set three-quarters of an inch from the netting. The plants started to bloom in June and continued flowering for five months. Lath screens were used to protect the plants from the direct sunlight.

When first planted, the basins were filled with water touching the seedbed. After the seedbed was soaked, the water was lowered so that a three-quarter inch air space intervened. When the plants were about an inch high, a half ounce of the basic formula was added around the plants three inches from

the bulbs. Two applications were made during the season in addition to the two pounds of the basic formula added directly to the solution.

Begonias have a low iron requirement and low light tolerance. They have short roots. Although the plants can withstand considerable misuse, nevertheless for high-quality prize specimens you should give careful attention to the plants, providing them with a moist but not wet seedbed. A solution temperature of 65 degrees Fahrenheit and the air temperature between 70 and 80 degrees with protection from direct sunlight is ideal.

Fig. 47. The first hydroponicum for begonias, by Vetterle & Reinelt, 1934.

CHAPTER SEVENTEEN

Flowering Woody Perennials

THE PERENNIAL flowering shrubs can be segregated into three classes, depending upon the hardness of their wood. Roses, gardenias, and fuchsias are representative of the three groups. Roses generally have the hardest and fuchsias the softest wood of the three. The order is based on the character of the roots as well as on that of the stems and branches of the plants.

The three species mentioned produce different root systems. The rose has long, thick, woody roots from which small feeding roots grow. The fuchsia has fewer thick roots and more fine, shallow roots like those of an annual. The origin of the fine feeding roots is more centralized, as they arise chiefly from the root crown. The root system of the gardenia stands between these two types, having some of the characteristics of both.

The adaptability of hard-wood shrubs to hydroponics is directly related to the readiness with which they form new roots. The harder the wood, the more difficult it is for the shrub to root and obtain the desired root-type. The fuchsia is easier to start from a green cutting than is the gardenia, and the gardenia in its turn is easier to start than the rose.

The root system of these perennials must be considered in terms of the growth habits of the plants. The rose can stand colder weather than the other two and drops its leaves in the winter. Like other hardy shrubs grown in cold climates it goes through a well-defined period of dormancy. Not so the gardenia, which is an evergreen. The fuchsia is semi-deciduous,

and under favorable conditions does not have easily recognizable periods of dormancy.

When roses are grown under glass in an artificially heated greenhouse as a forcing crop, they do not go dormant. And if forced too long without being allowed a period of dormancy, they lose their vigor.

The more the root system of a hardy perennial resembles that of an annual, the easier it is to grow by hydroponics. Fuchsias, for example, can be grown like an annual in a shallow seedbed, two to three inches deep. Gardenias require a little deeper bed to provide room for some woody roots besides those fine roots at the surface. The roses that do not develop fine surface roots from the crown require a deep seedbed for protection of the thick, woody roots.

Knowing that thick, woody roots will not develop to normal size or structure when immersed in liquid, you can picture what will happen when these three species are set into nutrient solutions. Feeding roots of the fuchsia will appear as fine threads leading down from the root crown, spreading out through the seedbed into the solution. The gardenia will produce an abundance of roots in the seedbed and solution, as they will grow from both the root crown and the thick, main roots. In the rose the feeding roots will be produced entirely from the thick, woody roots.

Fuchsias

While the fuchsia is a tropical flower, its best growing season is during the cooler months. It cannot thrive under intense sunlight and heat. Under hydroponic conditions, cultivation of the fuchsia can be extended beyond its present bounds.

There is no flowering shrub for which protection from unfavorable cultural conditions can be more simply provided. Because of its surface rooting and preference for shade, the fuchsia presents no serious aeration or iron deficiency problems. Its ready ability to produce new roots means greater powers of recuperation from poor cultural conditions.

When growing fuchsias in a cold climate where they will need to be protected in the winter, plant them so that they can

easily be removed from the seedbed. One simple way of doing this is to form wire netting into a jar shape, and fill it with litter. Place the plant in this litter and then set the whole thing into the seedbed. As it grows, the plant will send its roots through the wire netting surrounding it. When the end of the outdoor growing season arrives, simply pull up the wire form, with the plant. Cut off the roots protruding through the netting and store the plants in some place where they will be protected but will not dry out. Wire frames holding from one to two gallons of litter should be large enough for average-size plants.

Gardenias

The gardenia, a warm-weather plant, is extensively grown in greenhouses. It ranks behind roses and fuchsias as a garden flower except in warm climates. Even in warm climates where it can be grown outdoors the gardenia must be protected from intense sunlight. Belmont, Floribundia, and Cape Jasmine are the three varieties of gardenias which have been grown by hydroponics. Gardenia is an easier crop to handle than rose so far as nutrition is concerned, but it is sensitive to climatic factors.

Planting Gardenias

Gardenias are usually started as cuttings placed in coarse sand. When rooted, they are planted in pots or in large flats. Seedlings are ready for transplanting when they have several branches. Take the seedlings with attached soil and place them on the wire netting, inserting some of the new roots in the solution, and keeping the root crotch three to four inches above. Young stock would grow if roots were not placed in the solution, and cuttings will root in the litter bed if kept sufficiently warm and moist. Old plants should have some roots removed, and the ball of soil in which they are held should not be too large, as its greater water-holding capacity would make unequal distribution of moisture in the seedbed. (It would cause a situation similar to that of Guinea Gold Marigold described in Chapter XV, on herbaceous flowers.) Gardenias re-

quire more humid air and can withstand more moisture in the seedbed than roses or fuchsias. Their aeration is also less exacting than that of the two woody perennials. Four inches of coarse litter that will not settle too much will provide ample room for surface root growth.

To what extent the nutrition of gardenias varies from that of other woody perennials is a matter for further experimentation. The basic formula proved very successful when applied in the solution and on the seedbed in the same manner as described for other crops. Quality in gardenia flowers varies greatly with rate of growth, and closer timing of cutting of blooms is required. The blooms are cut when fully opened, unlike roses, which are cut as the buds begin to unfold. If growth of new shoots is interrupted and the wood hardens, the flowers will not be of good quality. The drop of buds, which varies somewhat with season, can be very serious.

These points, together with the importance of having new shoots come soon after cutting the flowers, suggest that the nutrition of the gardenia may be considered as having a nutritional pattern similar to the early growth stage of annuals. Their culture should be designed to induce abundant vegetative growth. You might add ammonium phosphate or ammonium nitrate or both to the seedbed; also an alternation of the basic formula with other solutions at different seasons might prove helpful.

Roses

The rose was the first and the hardest floral crop to grow by hydroponics, but it also proved to be a good choice for experimentation. It gave the clue to the type of experimentation needed to establish the principles of soilless crop production. It showed that the determining factor would be a cultural technique that would provide the different parts of the plants with a climate in conformity with nature's pattern.

The experiments will be described here briefly to bring out various essential points.

The rose is a hardy perennial. Most roses are budded or grafted; the root is of a different species from the stock. The

purpose of hybridization, grafting, and budding has been to obtain better plants for growth in soil. Thus, a rose developed for soil may not do as well in nutrient solutions as will the pure species.

Fig. 48. Roses develop good roots if the root crown is not submerged. Moisture-saturated air occupies two-fifths of the volume of the jars.

The first experiments with roses were started in January, 1927. The plants were set in one-gallon jars with three-inch necks. Two-year-old nursery stock was used and held in place by cotton wadding. The root crowns were held above the solution in a moisture-saturated atmosphere as the wadding prevented dry air from coming into the tops of the jars.

All varieties did well during the first year, although there was evidence that all were not equally suited to hydroponic conditions. The next year they declined.

In the next experiment roses were planted in large basins under glass. Some varieties started out well but none of them equalled roses grown in soil. This proved to be due to the high reflection of light and heat from the fibrous mat used to hold the plants in place, and also to the fact that dry air was allowed to reach the root crowns.

Roses were tried for the third time in the following May. The basins were out of doors and the plants were wedged between strips of board. A matting was placed over the basins. This was covered with soil which did not reflect light or heat. In this test some varieties did well and equalled those grown in soil. Others again failed.

It now became obvious that the seedbed had a most decisive influence on the plants in that it largely determined the climatic conditions under which they lived. This function of the seedbed as a climatic agency has since been found to vary with the season at which roses are planted. Varieties range from early to late. They do not all start at the same time to produce roots, leaves, or flowers after being rooted, or even after becoming established in the solution. Roots should be produced before shoots. If the plants are set out early, while the stock is dormant, the new roots will normally form before or with the leaves. If they are planted as late as April or May, the plants may develop leaves without making roots and, even though roots appear later, may never grow satisfactorily.

Root stocks to which roses are budded or grafted are selected for their beneficial effect upon their scion as well as for their own properties. Scientists use the term "affinity" to describe the relative adaptability of two species to each other when they are joined in this way. Because of the effect of hydroponic conditions on root development in general and the influence of planting time on the dormancy of the stock when it is placed in the nutrient solution, the technique for growing roses in basins must be designed to meet problems which do not arise when they are grown in soil.

Another factor of great importance in rose culture bears on the rooting properties of the plants. Varieties budded to the same root stock do not necessarily produce similar root systems.

Fig. 49. One of the earliest experiments with roses in 1929, to determine the suitability of seedbeds. The asphalt mat reflected too much heat and interfered with aeration.

Consequently, they differ in the relation of their parts to the three zones of environment described in the chapter on seedbeds. The placing of a plant an inch deeper or shallower than normal is much more important in hydroponics than in agriculture. Plants started in soil and then transplanted to the seedbed will usually have several large roots. These should be cut back until only about three inches of root are immersed in the solution.

Roses must be protected from excessive temperatures. Excessive temperatures cannot be determined merely by that of the air. The side of the rose exposed to sunlight might range in temperature from 100 to 120 degrees when the air temperature is 80 degrees. Seedbeds of high reflective properties accentuate this condition. This point is easily illustrated by looking at the results of an experiment in which two-year-old nursery roses of several varieties were grown in association with chrysanthemums. The latter were small plants which had been started from green cuttings. Planting was done in late April. At first none of the roses grew well. But later after the chrysanthemums had grown to such size that they partially shaded them, the roses began to develop and produced new shoots two to three feet long arising from the base, with quality flowers.

Depth of Planting

Roses planted in the garden are usually set an inch or two deeper than in the nursery, so that soil covers the point where the graft or bud was inserted. The distance from this point to the crotch of the main roots ranges from two to five inches, depending on the variety of rose being grown. We shall refer to this part of the plant and another inch or two of the main roots below the crotch as the root crown. The root crown should never be immersed in the liquid solution. Therefore, in planting roses, insert the main roots through several meshes of two-inch wire netting into the liquid, keeping the crotch an inch or two above. Then pack straw or excelsior around each plant, adding from three to six inches of litter, depending on the variety and climate. You should select varieties that start

shoots low. Deep litter protects these buds from heat. Picture your hydroponic rose garden consisting of basins with two to four inches of water, two to three inches of air space between the seedbed and water, and three or more inches of moist coarse litter above the crotch. Depth of water, air space, and character of the litter is adjusted to the plants' need for air. You can top the litter with soil to make it less conspicuous. In cool regions, a shallower seedbed can be used.

Most rose varieties bloom in the first year after planting. Thus, when you obtain two-year-old stock from a nursery, it has already been grown for a year after budding.

In selecting roses to be grown in bottles, choose short, husky varieties having glossy foliage and capable of blooming several times during each growing season. Among the hybrid tea roses suitable for this type of culture are the Madame Edouard Herriot, Talisman, and Golden State. Some of the polyantha types, such as Crimson Rambler, also make very effective floral decorations. This last variety has good rooting properties and does very well in nutrient solutions.

Roses are extremely responsive to climatic influences and the experimental data given may not hold for all sections as it does for that around Berkeley. Therefore, you should be careful to use varieties which easily produce new roots from those thick ones which are developed during the early growth in soil.

When planting roses in bottles, first cut the roots back to within three or four inches of the root crown. Compress them and force them through the neck of the bottle. Then wedge the plant in tightly with cotton wadding, excelsior, or some other fibrous material. The root crown should be above the level of the solution. At first the bottle may be filled to within two inches of the top. After a good growth of new roots has appeared, the solution may be allowed to drop an inch or two lower.

If the water used comes from lakes, rivers, or large mountain streams, four grams, or about one-seventh of an ounce, of the basic chemical formula will supply the needed nutrients to a one-gallon jar. This quantity should be added about once a month. Until you become familiar with iron deficiency symp-

toms, a few drops of a 3 per cent iron solution should also be added about twice a week. The nutrient solution should be kept on the acid side between 5 and 6 on the *p*H scale. Complete renewal of the solution every two or three months is desirable, especially if the flowers are growing rapidly.

You will obtain the best results with roses by planting them as early in the spring as possible. They must not be exposed to extreme heat or cold and should receive ample but not intense sunlight. The proper temperature range for both outdoor and greenhouse culture is between 65 and 80 degrees Fahrenheit. After the first flush of their blooming, some varieties may start to decline. They may then be transplanted from the bottles to soil and used again the next year. In large-scale production, the cultural technique is designed to provide roses grown continuously in litter with a rest period needed by perennials if they are to remain vigorous.

The branches should be pruned during dormancy and after every blooming. When roses are grown in soil, there is no root pruning after planting. It is possible that pruning may be necessary for some plants in hydroponics but an opinion as to the method to be used cannot be ventured until further experiments have been carried out.

In closing I wish to warn you again that there is no substitute for that principle, perhaps a bit worn from frequent usage in this book but nonetheless fundamental, which teaches the necessity for knowing each plant intimately so that its slightest reaction to changes in growing conditions may be recognized and the proper steps taken to correct any untoward effects.

CHAPTER EIGHTEEN

Commercial, Garden, and Home Production

WHETHER you desire to use hydroponics on a large scale in a commercial venture or on a small scale at your home, you must first find out if it is adapted to your own particular situation. In most cases this question resolves itself into one of the relative cost of hydroponics and agriculture. Therefore, let us look into the expense which you may expect to incur in setting up and operating a hydroponicum.

The commercial plants now in operation are of an experimental nature and the investment they represent does not offer a true picture of the eventual cost of a commercial hydroponicum. However, for the purpose of comparison, let us consider that you wish to build your basins of durable material, such as concrete, California redwood, or eastern cypress. Basins of these materials may cost about ten cents per square foot and the wire netting with frame attached an additional two cents per square foot. Twelve cents per square foot, a conservative estimate when building-trade prices are considered, would bring the cost of an acre of tank space to $5,000, or fifty times the cost of an average acre of farm land. It is almost certain, however, that basins of much less expensive materials can be designed in the future for use in various sections.

If production is under glass, hydroponics will not add a major item to the cost of the greenhouse. Fifteen or 20 per cent

of the cost of the building proper could be charged off to this equipment. Actually, the cost of a hydroponic greenhouse should be less than that of an ordinary one fitted with benches and facilities for heating and sterilizing soil, and considerably less than that of a greenhouse equipped to grow plants in sand or cinders. Greenhouse costs run from around sixty cents to more than a dollar per square foot of ground area, or roughly

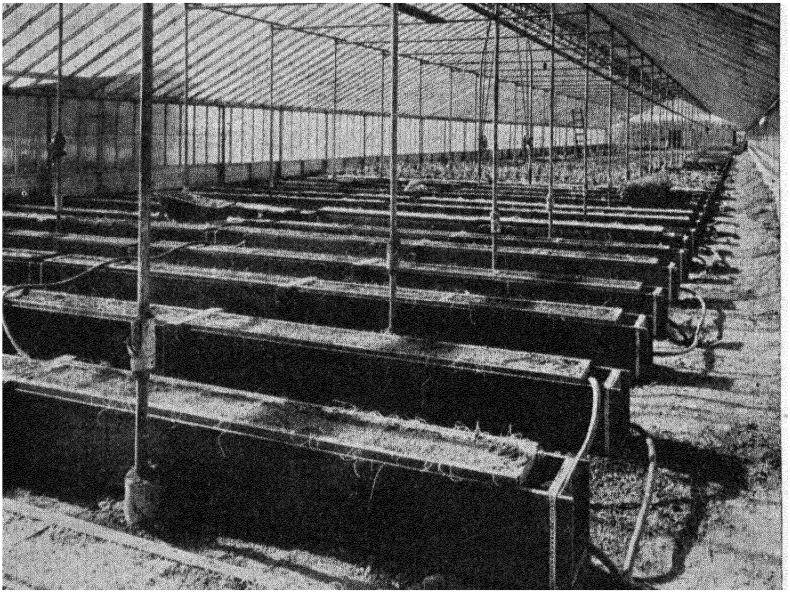

Fig. 50. The first commercial hydroponicum built of redwood. Basins one foot wide and 36 feet long have been in use five years. The solutions circulate through the basins.

from $25,000 to $50,000 per acre. The higher cost comes where wind and snow add to the burden the building must carry, requiring more substantial construction.

Competition with Agriculture

Before hydroponics can compete with agriculture in producing a certain crop, the cost of chemicals must be markedly lower than the average price paid for the crop. If this is the

case, you will have a margin of proceeds to apply on the cost of labor and interest on the capital investment. Whether this margin will be large enough to provide a net profit will depend upon yield. Any cost can be justified so long as it provides a corresponding increase in yield or quality of the product.

Crops designated as having high, medium, and low chemical costs are: (high) the small grain cereals, such as wheat, rice, rye, barley, oats, and the sorghums, as well as the strictly fiber

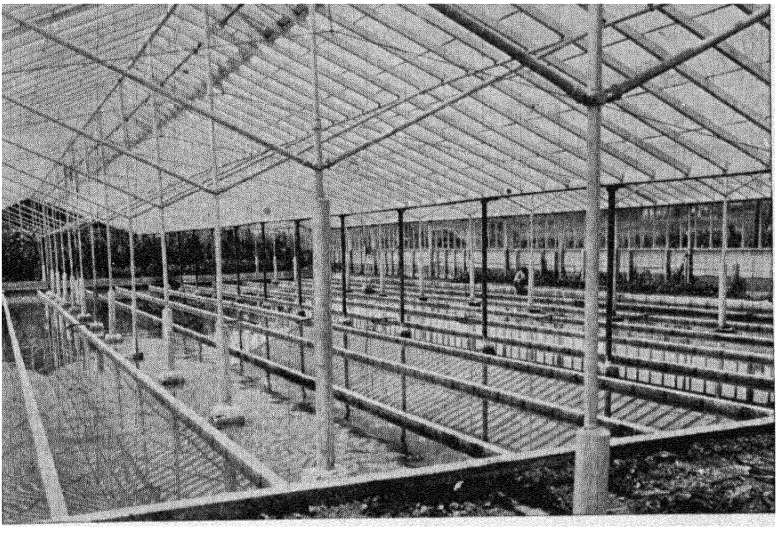

Fig. 51. Large concrete basins are used in some plants.

or forage crops; (medium) some of the field corps which are high in sugar and starch, such as corn and sugar cane, and the high protein vegetables, like peas, and beans; (low) crops high in water, starch, and sugar, including the tuber crops, and most of the vegetables and flowers.

Crops may also be grouped in terms of their production in competition with agriculture. The groupings include: (1) those that cannot outyield agriculture, (2) those that can, and (3) those that can but only when grown in association with another crop. The first group includes those crops that cannot be sown more closely than is possible in agriculture, such as the

small grain cereals and sugar cane, and those whose stand is determined by the space needed for havesting, such as some floral crops grown in greenhouses. In the second group are the crops that can be planted more closely than is possible in agriculture. They include corn, potatoes, tobacco, and most garden vegetables. The third group contains crops which can be grown in combination with others so that the aggregate yield of the area planted exceeds that achieved with the single-crop system of agriculture.

Food Requirements and Yields

Commercially operated plants are as yet unable to offer complete information on the practical minimum plant-food requirements of various crops. The minimum compositions of the crops as determined by laboratory experimentation offer suggestions. It is necessary to figure not only the amount of food actually absorbed by the plants but also that amount which is lost during operation of the hydroponicum. Under some circumstances the latter portion may be quite large. This is especially true where occasional drainage of the solution becomes necessary. Nevertheless, though loss may be incurred through occasional necessary drainage, the chemical cost of producing many crops is lower in hydroponics than in agriculture.

Acre yields expressed in such terms as bushels and tons are largely determined by the part of the plant which is used and the form in which it is marketed. Strictly fiber and forage crops are usually sold green or dried, and consist of the entire plant except for its roots. Thus acre yields expressed in pounds might appear high. In cereals, acre yields similarly expressed are comparatively small because the merchantable product, the grain, comprises only a fraction of the total weight of the plant. Tuber and root crops give high tonnage yields because practically the entire plant is marketed. From these considerations it becomes obvious that differences in yields of green vegetation of the various crops per acre are not so large as production figures might indicate. Also, that while the cost of chemicals per

unit of dry matter produced may not vary so widely among different crops, the cost of chemicals when expressed in terms of production units may vary greatly.

Cost Estimates

From data on the amount of plant food required to produce a bushel, ton, or other unit of yield, and the probable yield per acre of tank space, you can estimate the cost of hydroponic production in any crop. Table IX offers you such an estimate for ten crops. The table is designed as a model for estimates rather than as a basis for them. It gives the amount of plant food experiments have indicated would be the order of the magnitude for various crops rather than the actual requirements. Even a 50 per cent variation either way in the amount of plant food shown as required in the table will not, however, alter the essential relationships.

TABLE IX

Amount and Cost of Plant Food Required to Produce a Ton of Merchantable Product and Market Value of This Amount

(Ten Representative Crops)

Crop	*Amount of Plant Food (pounds)*	*Cost of Plant Food*	*Market Price*	*Value of Crop*
Potatoes	100	$ 3.00	.50¢ per bu.	$16.65
Onions	100	3.00	$ 1.00 per cwt.	20.00
Tomatoes	125	3.75	$15.00 per ton	15.00
Red Beets	150	4.50	.01¢ per bunch	20.00
Carrots	150	4.50	.01¢ per bunch	20.00
Corn	400	12.00	.50¢ per bushel	17.85
Beans	500	15.00	$ 3.50 per cwt.	35.00
Rice	600	18.00	.60¢ per bushel	24.65
Barley	800	24.00	.50¢ per bushel	20.85
Wheat	1000	30.00	.90¢ per bushel	30.00

Yields of floral crops are stated by count. It is difficult to give their food requirement per unit of production because of the many factors that affect the ratio of merchantable flowers to the vegetative growth of the plant. Practically all flowers are in the low chemical-cost classification.

The actual plant food the crops required was about one-third of the weight of the chemicals. The rest is oxygen and

sulfur, which should not be counted. Although a little sulfur is needed as food, that supplied as sulfuric acid must be classed with oxygen, as adding weight but not food substance in the data on plant food requirement. The food requirement as expressed by the weight of the chemicals used varies with cultural conditions. If conditions are good and yields are high, the figures are low. In the data given, the cultural conditions were good and the yields high.

Another classification showing why chemical costs vary among crops is the ratio of weight of products and plants. Crops can be placed in three groups: (1) those of which the product weighs more than the plant, as in the case of tomatoes, cucumbers, and melons, which continue growing while bearing, (2) those of which the harvest constitutes the greater part of the green weight of the plant, as in the case of potatoes, root vegetables, and leaf vegetables, (3) those of which the harvest constitutes the minor part of the green or dry weight of the plant. All cereal grains, corn, and cotton come in this classification.

Floral crops fall in all three groups. Where cultural conditions are unfavorable, crops belonging in groups (1) and (2) might fall in group (3), at which their chemical cost will increase appreciably.

It is shown in the case of potatoes that, when the yield can be conservatively estimated at from one to two thousand bushels per acre, the cost of chemicals held at $100 per acre, and the price of the product at a low figure of fifty cents per bushel, there will be sufficient margin to amortize the investment over the life of such durable equipment as concrete basins. In crops of high chemical cost and low tonnage, hydroponics cannot compete with agriculture.

Water is far too high for commercial production if it has to be purchased at the rates commonly charged by city water systems. This is true despite the fact that hydroponic water requirements usually are lower than those in agriculture. Water should be made available at the same prices as for irrigation in agriculture. You may find it possible to drill your own well, in which case the cost of water is low or negligible.

Comparison of labor cost or of production per man of the

two systems is still a matter of conjecture in the absence of complete data. Soilless crop production is essentially hand labor and is to be compared with hand labor methods of agriculture. Machine production methods of agriculture apply principally to high chemical cost crops naturally excluded from hydroponics. The general belief of those using hydroponics is that labor cost is less than that of agriculture for comparable situations.

Hydroponics in Homes

Inquiries have been received from persons seeking directions for growing vegetables and flowers by hydroponics in homes

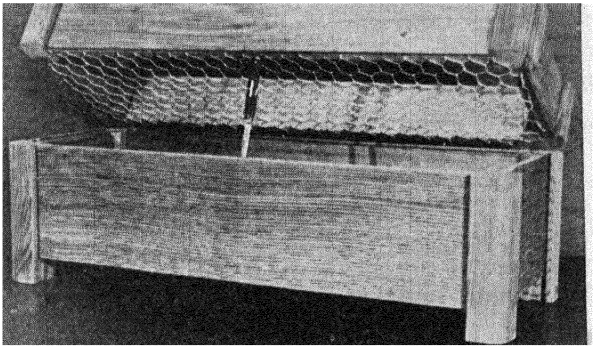

Fig. 52. Attractive window box of redwood designed by Morton Smith, Hammond Lumber Co., San Francisco.

during the winter, and in moving trailers, and in ships. Such operations offer difficulties that undoubtedly will prove almost insurmountable unless you have already mastered the art of hydroponics. Limited success is not impossible if you are familiar with the art and apply yourselves thoughtfully to the problems involved.

For house production your choice for green food must narrow down to plants which have low light requirements and do not need great variation in root-top temperatures between day and night. While almost all vegetables are thus excluded, nevertheless you can grow delicious sprouts of edible seeds like

peas and beans. Light is not necessary for germination and sprouting of the seeds, but in order to increase the vitamin content of the sprouts they should be exposed to sunlight as much as possible. The seed can be sown on a screen stretched over a basin of nutrient solution or tap water. Germination will be hastened if the liquid is kept at a temperature between 70 and 80 degrees Fahrenheit.

Under the same treatment you can produce leaves to be used as greens from the storage roots such as beets. The seed pieces themselves—that is, the full-grown beet roots—contain enough food to enable the plant to produce leaves, but they should be exposed to light to increase green color. A deep seedbed would be required for large storage roots, which would be planted with the top flush with the surface of the litter, and kept moist until feeding roots are established in the nutrient solution. The storage root will grow only after it has passed through a normal rest period.

Floral plants normally grown in the house can be grown in nutrient solutions, but the poor root system of plants with low light requirements makes them unsuited for the beginner. Success in growing house plants will depend largely on having a proper seedbed.

Production Hints Summarized

A few hints which have been covered in other parts of the book may well be summarized again for your convenience. First, know the composition of the water you intend to use. Unless you know the quantity and character of the different solutes it contains, you cannot devise a formula to make the most economical use of water and chemicals. Second, remember that physiological problems transcend all others in hydroponics. The requirements of certain plants for different temperatures and atmospheric conditions during day and night have shown the possibilities for air conditioning of greenhouses. However, you should never try to adjust the plants to artificial conditions. Rather the conditions should be adjusted, artificially if necessary, to the natural needs of the plants. Third

the foremost consideration in establishing a hydroponicum, either outdoors or under glass, must be sunlight. Sections which do not have ample sunlight cannot compete with those that do. Fourth, in garden production, remember that neighboring objects such as trees, houses, and fences may greatly affect the climate conditions around the hydroponicum, particularly by affecting the supply of sunlight at certain times of the day. It is important to realize what these influences may be and to plan for them.

CHAPTER NINETEEN

Mineral Composition of Plants

PLANTS vary widely in their mineral composition. Some fresh-water plants contain less than 1 per cent of mineral elements. Of certain desert species, more than 20 per cent of weight is due to substances absorbed from the soil. The variation within and between different species raises the question: Can all plants be grown from the same chemical formula in hydroponics? As we have learned, the answer is "Yes," and the proportion of various salts in the formula should follow their minimum proportions at maturity in the plants being grown. Nevertheless, the answer may be a bit too categoric, for we can alter composition of a plant within certain limits by changing the chemical formula used, or by providing the same mixture of plant food and altering climatic conditions.

The nitrogen content of wheat, for example, ranges among the many varieties from a fraction above 1 per cent to more than 4 per cent. Each variety has a minimum and maximum content, but the lowest maximum is always much higher than the highest minimum. Consequently, there is a range among all varieties in which they can contain the same percentage of this element.

Variation in nitrogen content among plants is due to the individual differences in the amounts they absorb during their latter growth period. This fact makes it possible to alter hydroponic technique in such a way as to obtain at will any desired percentage content within the variety's range. Conse-

quently, we could arrange to have all varieties contain the same amount. Plants grown under diverse conditions can be forced to have the same composition, and plants grown under the same conditions to have differing compositions. All that we need to know is the minimum and maximum contents of each element in the plant at maturity and the growth stage at which various quotas of each substance are absorbed.

The amount of each element in the plant is the sum of two things: (1) that which is actually needed, and (2) that which is absorbed as an excess. The latter cannot be taken in until the first need has been satisfied; that is, not until late in life. It does not aid in the production of vegetation, but it does influence the composition of the plant at maturity.

The way in which plants alter the mineral composition of their various growing parts as life progresses toward maturity has an important bearing on development of cultural technique for the purpose of altering the mineral content of plant products. The nitrogen content of wheat again offers a good example. Before the grain is formed, this element is quite uniformly distributed throughout the plant. Then, as the wheat begins to head, nitrogen moves from the roots, leaves, and other parts into the forming kernels. Finally, at maturity, the grain contains a much higher percentage of nitrogen than do the other parts of the plant.

Devising the Technique

Three classes of products must be considered in devising the technique to be used in changing plant composition. These are: (1) the ash, or what remains after complete burning of the plant, which contains all of the elements derived from soil or nutrient solution except nitrogen; (2) protein, which in wheat comprises 5.7 and in some other plants 6.25 times the percentage content of nitrogen; (3) carbohydrates, such as sugar and starch, and other products such as plant oils.

There is no practical way to influence the sugar, starch, oil, or fat content of plants directly by mineral nutrition. Excessive feeding of nitrogen during the latter growth stages of beets

and cane will reduce their sugar content. Also, since protein and carbohydrate stand in complementary relation to each other, creation of conditions whereby the highest possible protein content is obtained will reduce the starch. Outside of these factors, however, variation in sugar and essential oils is more subject to climatic conditions than to mineral nutrition.

Most of the experimental work on composition has been done with wheat and tomatoes. The baking properties of wheat flour are influenced by the content and quality of the protein in the grain. By applying nitrogen to the soil during the late growing stage, the farmer can produce a high-protein grain. He can also influence the quality of the protein, for the character of the plant sap determines whether or not the protein will be good and the sap can be modified by mineral nutrition. This has been done successfully with crops grown hydroponically, but is commercially not practicable.

Wheat was grown in basins containing the basic nutrient solution. Before the heads appeared, the solution was drained and replaced by one salt, which provided only two elements. The salts tested are given in Chapter XIV, on field crops. The sap of plants is composed of water, elements absorbed from the solution, and substances synthesized by the plants, themselves. When only two elements are available for absorption instead of eleven, the sap naturally contains a much higher percentage of these two than is normally the case.

Aside from nitrogen, the principal mineral elements in wheat grain are phosphorus, sulfur, calcium, and magnesium. Because sulfur is part of the protein molecule, it varies with the nitrogen content. The range of variation for phosphorus is not so large, as that of nitrogen, the possible increase being about two times the minimum. Data are not complete for calcium and magnesium.

You should not infer from the information given that the grain is the only part of the plant in which a wide range of variation in mineral content is possible. Some of the elements which have a low range in the grain may have a very wide range in the other plant parts.

Conditions for Composition Change

Two conditions are necessary for the alteration of plant composition through mineral nutrition: (1) withholding of certain elements from the nutrient solution, and (2) adding certain other elements to the solution during the latter growth stage. Neither of these expedients will have any effect unless the plants are still growing and able to absorb nutrients. Thus, the first prerequisite is that the plants must have good growing conditions, so that they will create an efficient absorbing mechanism. After this has been obtained, the culture medium (solution) is altered. To do this, drain the solution and replace with one devoid of those ions which are absorbed more easily than the elements you want absorbed in large quantities.

Let us suppose that the object is to have the plant absorb large quantities of phosphorus, which has a negative charge. Nitrogen in the form of nitrate also has a negative sign and is absorbed much more readily than phosphorus. Thus, its presence in the solution will restrict the phosphorus intake. Furthermore, nitrogen is an essential food element and must be available to the crop until vegetative development is well advanced. After this stage has been reached and before the plants have stopped growing, however, the basic solution can be removed. The basins are then refilled with water. Calcium phosphate, magnesium sulfate, and potassium phosphate are added, but no nitrogen. As already pointed out, positive and negative elements in the solution are absorbed in substantially the same proportions, or, if not, the solution changes reaction. The positive calcium, potassium, and magnesium will be balanced principally by negative phosphorus. Sulfur is also negative but will not influence the phosphorus intake very much because it is not readily absorbed. Magnesium phosphate can be used instead of the sulfate. Phosphorus will constitute by far the bulk of the negative elements absorbed and its content in the plant will be much higher than normal.

Such an objective as that just described can be reached only in hydroponics. It is impossible in argriculture. Even when large applications of phosphorus are made to the soil in the

form of fertilizer, its intake will be restricted because the plants, by selective absorption, will seek out the nitrogen in the soil. The latter element cannot be eliminated from the soil as it can be in hydroponics, where the process consists simply of draining the basic solution from the basin.

Examples of the effectiveness of this technique can be taken from hydroponic experiments already completed. When phosphorus was removed from a solution nourishing wheat plants after they were four weeks old, the straw at maturity was only .029 per cent phosphorus. In another case where, after the wheat was six weeks old, nitrogen was removed from the solution to allow increased absorption of phosphorus, the straw at harvest contained 1.1 per cent of phosphorus; that is a forty-fold or 4,000 per cent increase over the first example. There is reason to believe that even this large content can be exceeded. In another experiment, the calcium content of straw of plants grown in nutrient solution devoid of this element from the six weeks' growth period to maturity was .015 per cent. A twenty-fold increase—.30 per cent—was obtained when the same plants were deprived of potassium to permit further absorption of calcium.

Controlling Tomato Composition

At present the tomato is the only vegetable produced commercially by hydroponics whose mineral composition is known. The contrasting mineral contents of tomatoes grown in soil and nutrient solution are given in Table X. There is every indication from these figures and those obtained in experiments with wheat that vegetables of unique mineral composition and dietary value may be grown by hydroponics. The leafy vegetables and the root crops will be even better adapted than tomatoes to such production.

TABLE X

Mineral Composition of Tomatoes

Production Method	*Potash* K_2O	*Phosphate* $PO_4^{\equiv}$	*Magnesia* MgO	*Sulfate* $SO_4^{=}$	*Lime* CaO
Agriculture	.99	.21	.05	.06	.20
Hydroponics	1.63	.33	.10	.11	.28

The mineral content of tomatoes grown by agriculture can be as high as that of those produced hydroponically. But the farmer cannot alter the composition of his fruit at will as can the soilless gardener. Tomatoes grown by hydroponics have been called "mineralized." This is a good merchandizing term but may give an erroneous impression of the physiological factors involved in altering the composition of the fruit. There is no essential difference in the processes of mineral nutrition whether tomatoes are grown in soil or in nutrient solution. The ability to produce tomatoes of very high quality by hydroponics is the result of the control over climatic factors afforded by the method.

Variations in the percentage composition of the elements in plants are not correlated to variations in yield; nevertheless, they should not be considered independent of yields in studying the factors influencing production. The amount of growth a plant can make from a given quantity of food still depends upon the percentage which it holds inside its tissue. This percentage varies with the size and age of the plant, as well as with the character of the nutrient solution. For example, let us turn again to experiments with wheat. In Chapter XIV, on field crops, you will find a table giving the various one-salt solutions in which wheat was grown for about one-half of its total growth period, in order to alter its composition.

Ammonium Salts

Wheat grown in a solution of ammonium nitrate surpassed that grown in all other solutions in size of heads and stalks, but was inferior to others in the quality of the grain. From these experiments it was learned (1) that wheat and other cereals, after they are about half-grown, no longer require all the elements necessary during early growth stage; (2) that nitrogen is chiefly responsible for the development of tall, sturdy stalks and high-protein wheat grain; (3) that the tallest stalks and largest yields are not obtained when the basic formula is maintained in the solution throughout the growth period.

Thus it is shown that the natural seasonal depletion of the

available nutrients in the soil is beneficial to crops. Plants absorb the soil nutrients faster than the soil can make them available. Finally, there comes a period when the soil solution is almost exhausted. The solution is restored during the natural season of fallow which is imposed by nature. Similarly, in hydroponics the supply of each element provided during the early growth stage of the crop should not remain constant throughout the crop's life if the most efficient use of nutrients is to be obtained.

I have said previously in this book that the amount of nitrogen required in the solution is determined by the amount of potassium it contains. This is true only until the plants have absorbed enough potassium to fill their minimum requirements. In wheat this stage is reached when the plants are about half-grown, provided sufficient potassium is in solution during the early growth stage. Other crops may require longer or shorter periods to reach this stage. But after it is reached the amount of potassium in the solution may be cut down. This can be done by replacing the original solution with one containing no potassium but sufficient nitrogen. Another way to obtain more efficient use of potassium is to have a wider ratio between these two elements at the beginning—that is, a different nutrient solution.

The basic formula does have more potassium in relation to nitrogen than wheat needs, but as this nutrient solution does not change reaction perceptibly with absorption of elements, it is well-suited for growing all kinds of crops without recourse to corrective measures necessary when the *p*H changes quickly.

Similar stimulation of yields by use of ammonium nitrate can be expected with other cereals, also some flowers and vegetables. It should improve barley yields but lower the malting quality of the grain. Rice should be benefited. Cotton also should be aided, since an increase in the length of the fibers is desirable.

Such vegetables as spinach, in which succulence is a desired trait, and flowers such as snap-dragons and gladioli, whose blooms are not impaired by rapid shoot growth, would also be helped.

Ammonium phosphate did not stimulate vegetative growth of

wheat as did ammonium nitrate, and the grain produced on this treatment had only fair milling and baking qualities, which were due to the fact that wheat requires about seven times as many nitrate as phosphate ions, while ammonium phosphate provides these elements in roughly the same quantities. The plants were unable to use the large amount of nitrogen required in the latter growth stages because of the continued presence of large amounts of phosphorus in the solution. Essentially, ammonium phosphate is a substance which should be used for developing young plants, not for stimulation of ripening processes. It is a good source of nitrogen and phosphorus for perennials like gardenias and roses, which continually produce new buds. It is also a good source of phosphorus when the solutions are made with water naturally high in calcium.

Ammonium sulfate and ammonium chloride both stimulated the growth of wheat during its latter growth stage more than did ammonium phosphate. The sulfate treatment produced grain with better milling qualities than did the chloride. The chloride ions were more easily absorbed by the plants than the sulfate ions. Since the ammonium ions are also easily taken in by the plants, the solution may become too acid and thus curtail growth if the sulfate treatment is used, unless corrective measures such as addition of ground limestone—$CaCO_3$—are used. The beneficial response of the plants to the sulfate treatment was due mainly to the nitrogen which was absorbed. In the case of the chloride treatment, on the other hand, the nature of the response hinges upon whether the chloride proves harmful or beneficial to processes carried on inside the plant. And this in turn is dependent upon the individual character of the different plants.

Calcium Salts

Calcium nitrate is the best chemical for nourishing wheat during its latter growth stage, as it produces the best bread, judged by baking standards. The grain was not markedly high in protein, as compared to other treatments, showing again that the amount of nitrogen crops absorb is influenced by the cation with which it is associated. Plants do not absorb cal-

cium to great excess. Calcium nitrate is probably the most important chemical that can be used to improve the quality of various vegetable crops when used in the manner described for wheat.

Calcium phosphate and calcium sulfate treatments had no apparent effect upon wheat. Calcium chloride was harmful.

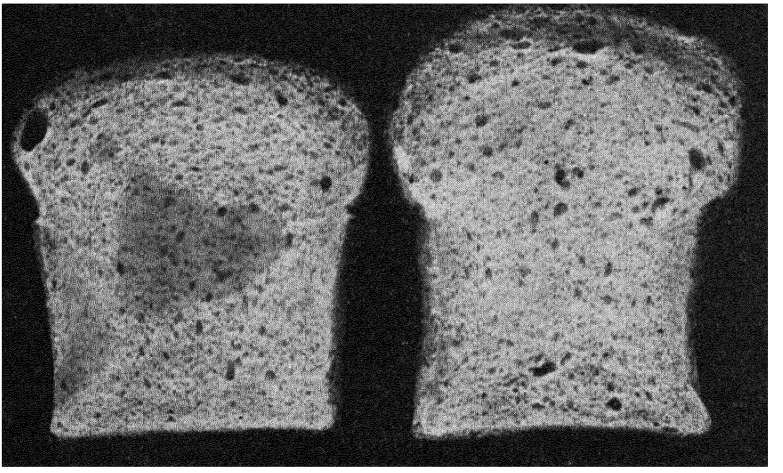

Fig. 53. Bread made of flour from wheat grown by hydroponics. The protein content of the samples is equal. The better bread, on the right, is from wheat grown in a solution of calcium nitrate, which replaced the basic formula when the plants had reached the heading stage.

Potassium Salts

Potassium nitrate produced the largest yields. Its effect during the latter growth stage was probably more noticeable than that of other elements because its chief distinctive effect appeared early. All cereal grains and most vegetable and floral crops made more growth from a milligram of potassium nitrate, added to water, than from an equal amount of any other chemical. The plants which did not do so were invariably those which did not have strong, sturdy stalks, branches, or vines.

The other potassium salts were generally harmful. Potassium sulfate proved to be too acid. Potassium phosphate added phosphorus, not essential to the plants during their later growth. And potassium chloride reduced the plants' intake of nitrogen.

Magnesium and Sodium Salts

Magnesium and sodium nitrate (the latter is known to the trade as Chile saltpetre) were good sources of nitrogen during the latter growth stage of wheat. The other magnesium and sodium salts were more or less harmful.

CHAPTER TWENTY

Sand Culture

SOME investigators and also greenhouse operators growing plants in sand, cinders, and gravel to which nutrient solutions are added have called this method of culture "soilless crop production." In consequence, some confusion has been caused as to the difference between "sand, cinders, and gravel culture," as this type of operation should be called, and hydroponics. Clarification of distinctions between the two requires a definition of soil.

Scientists are not agreed as to all the physical, chemical, and biological characteristics of the Earth's surface that should be included in the term *soil*. However, on certain general features that have been recognized, a definition can be based. The soil is a foundation in which, or on which, plants will grow if climate is favorable and water and nutrients are available. The various names given to soil—earth, land, ground—infer foundation and refer to that part of the Earth's surface which is composed of disintegrated or weathered rock holding liquid as a thin film on its particles. This liquid is known as the soil solution, and the nutrients contained in it are derived from the solid particles. Fertilizer also is dissolved into the solution. The fundamental difference between water culture and agriculture is that in the former the nutrient solution is in a free state and manifests hydrostatic properties, while in the latter it is held by surface attraction to the soil particles.

It has been contended that sand, cinders, and gravel treated

so that all nutrients have been removed are soilless, and that they remain so even after nutrients have been added to them. The inconsistency of this view is seen when we consider plant growth and its relationship to soil conditions. Many fertile fields are virtually depleted of available nutrients at the end of the growing season, hence approximate the state of treated sand, cinders, and gravel. They cannot produce another crop until their store of plant food has been replenished. Still we would not consider them soilless simply because they contain no nutrients. The presence or absence of one or more elements from the soil solution, thus making it fertile or unfertile, does not provide a basis for differentiation between the soil and soilless crop-production media. It is evident from its very nature that soil must be composed of at least a framework of insoluble particles. Nor does the method of adding nutrients offer a basis for differentiation. If it did, lands treated with fertilizer would have to be set apart from those whose nutrient supply is replenished by natural means.

As long as food elements are incorporated in the soil, they must be considered a part of it. This does not mean, however, that once they have been removed, the structure in which they were held is soilless, for their elimination from the soil does not alter its basic physical and geologic characteristics as part of the Earth's crust.

Another difference between soil and soilless culture is in the aeration of plant roots and root crowns. In agriculture, aeration is supplied through the pores between the soil particles. In soils saturated with water these spaces are filled, air is excluded, and plants die unless relief is provided through drainage, evaporation, or some other means of doing away with the excess moisture. The same situation holds in the case of sand, gravel, and cinders used for crop production. Plants will not grow in them if their pore spaces are filled with nutrient solution. Obviously, then, so far as aeration is concerned, they must be regarded as soil. The drainage of this excess then leaves the materials in a state which manifests the true characteristics of a soil: water held as a film by solid particles, also some water

held in the free state, its flow retarded by friction, and air space between the particles arising from drainage following saturation by rain or irrigation.

Applying Water to Coarse, Porous Solids

The surface area which holds water as a film in sand, cinders, and gravel is small compared to that of soils composed largely of fine clay particles. Therefore, more frequent watering is necessary to maintain adequate moisture for crops. Water, which can be a nutrient solution, can be supplied to sand, cinders, and gravel in three ways when used for crop production:

1. *The drip method.* The water is applied at a rate equal to its use by plants. The amount applied per unit area surface varies with the climatic conditions and with the kind and age of crops grown. The rate also is adjusted to prevent excess water from filling the pore space of the soil, thereby excluding essential air from the roots. Water-tight basins are not necessary, but considerable equipment may be required to obtain proper distribution of the water when used on a large scale.

2. *Flooding or submergence method.* This consists of flooding. The surface of the beds is flooded and the basins are filled, or water is pumped into the basins from below, thus raising the level of the solution. The pore spaces become filled with liquid which must be removed by drainage. Considerable equipment including pipes, pumps, reservoirs, and control apparatus is required for a system that maintains the required air-moisture relation by regulated flooding and draining several times a day.

3. *The suspension method.* Sand, cinders, or gravel is suspended immediately above a water surface held in a basin. The plants set or the seeds sown in the bed send their roots into the solution below. Apparatus for control application of water and maintenance of proper air-moisture relation of plant roots is not necessary. This is the hydroponic method. It requires the least outlay for equipment.

Uses of Coarse, Porous Solids

We see, then, that sand, gravel, and cinders are essentially soils of low solubility and low absorptive power. As such, they offer some advantages for greenhouse operation over fine soils containing more colloidal material. The latter are highly absorptive and are likely to undergo physical changes as a result of the treatment and conditions which go with greenhouse culture. Intensive cultivation, frequent applications of fertilizers and water, the concentration of roots, and the absence of influences naturally arising from weathering in the field all combine to render fine soil quickly unfit for use. Replacement of these with new soil is both expensive and inconvenient. Consequently, sand, gravel, and cinders, whose physical properties do not change perceptibly with treatment, would offer an advantage. Plant food can be provided by flooding them with nutrient solution at frequent intervals.

This system of culture may also have advantages over hydroponics for production of a limited number of crops. It is conducive to more extensive root growth than is hydroponics and also offers better anchorage for some plants. Thus, it is well-suited for growth of plants, which have relatively weak rooting power and require secure anchorage for their roots.

Plant Food for Coarse, Porous Solids

The basic hydroponic solutions may also be used for sand, cinder, and gravel culture. For greatest efficiency, however, consideration should be given to the character of the water and to the absorptive power of the material used. The composition of nutrient solutions passed through porous solids is altered by differential absorption and precipitation of salts on the solid surfaces of the particles. The smaller the amount of nutrients released or fixed by the solids, the more consideration must be given to the composition and concentration of the solution. Certain sands have very low absorptive properties and do not materially affect the composition of the solution. Where the water is low in solutes and the soil does not release or fix the

nutrients, the basic formula may be used. If the water is high in solutes, the composition of the solution should be altered just as in hydroponics. Again the fundamental principle for compounding the chemical formula is to provide the major elements in the quantities in which they are needed, to obtain the lowest chemical cost.

In practice, the nutrient solution for sand, cinders, and gravel culture does not require as careful compounding as in hydroponics. The materials ordinarily used are not wholly insoluble or inert; therefore they change the character of any nutrient solution added. Also they usually contain the minor elements, making further supply unnecessary. The alkaline character of some of the materials used, such as lime gravel, cinders, and synthetic gravel, prevents excess acidity. Furthermore, these materials usually do not contain the compounds that give rise to accumulation of alkalinity in soil. However, this advantage of less exactness in compounding formulas for coarse sand, cinders, or gravel should be balanced against the disadvantage of less efficient use of nutrients, where formulas cannot be maintained according to the plants' needs. The nutrients can be provided as solutions or applied as solids scattered on the surface, as is customary in agriculture. Larger quantities per unit volume of water or culture media than recommended for hydroponics can be used without harm. Considering that one cubic foot of porous solids holds about one fourth cubic foot of water and that the concentration of the nutrient solution used in hydroponics ranges from .05 to .2 per cent solutes, simple arithmetic will tell you how much nutrients should be applied to sand, cinders, or gravel.

History of Sand Culture

Sand culture has been used in laboratory experimentation at least since 1842. In that year the essential role of manganese in plant nutrition was established through very refined experiments, the plants being grown in beds of pure silica and platinum shavings. The first time sand was used in a demonstration for practical crop production was in 1929. Beds of

pure sand, 10 feet long by 2 feet wide and three inches deep, were held in basins holding nutrient solutions. In some cases nutrients were added to the sand only, in others to the water. Figures 54 and 55 show carrots and beans grown in sand beds suspended over nutrient solutions held in basins. The technique for providing water, air, and plant food to materials since called "soilless" by some investigators was established before hydroponics, the real earth-eliminating method, was de-

Fig. 54. Carrots grown in a three-inch bed of pure silica sand supported three-quarters of an inch above water in a basin. A nutrient solution made from the ordinary grade of chemicals used as land fertilizer, hitherto considered by plant physiologists as unsuited for water culture, supplied the essential elements. The commercial feasibility of sand culture for crop production was established in 1929.

veloped. In 1935 "gravelite," a synthetic light-weight gravel used for concrete construction, was used as seedbed material. It proved satisfactory for some crops.

The author's system with sand and gravel culture provided an air space below the seedbed to prevent saturation by capillary rise of water. The depth of the layer of sand and gravel seedbed was adjusted to the penetrating power of the roots, that is, to the character of the crop grown. The depth of the solution in the basin was determined by climatic conditions affecting the water requirement of the plants. The desirability

of adding some water at infrequent intervals required basins that were not too large; and to avoid too frequent additions, the basins must be of sufficient size. As already pointed out, the principle is to have the quantity of nutrient solution available, per unit area of surface planted to crops, follow Nature's pattern. The periodic saturation of soils by rain, the removal of excess water by drainage, and the depth of the root zone give the physiological basis for the equipment designed to provide the proper moisture-air relationship for plant roots.

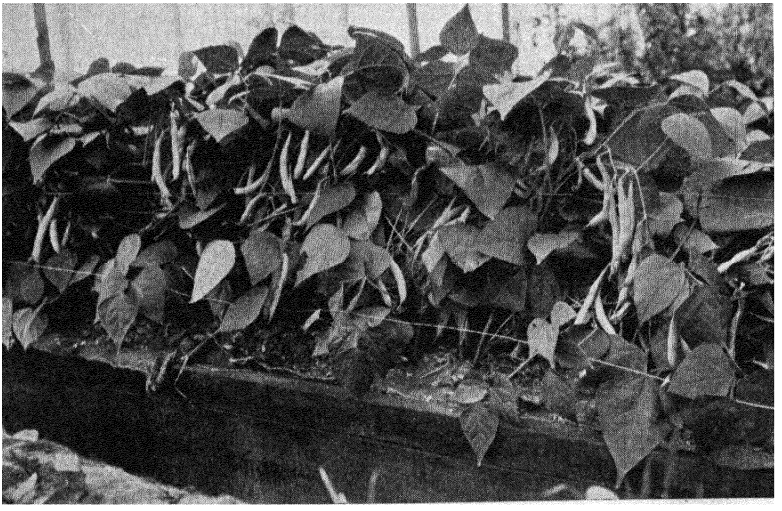

Fig. 55. Beans two months after planting in a bed of coarse, impure sand mounted in a basin with nutrient solution below.

Soil Beds Mounted Over Water

It is not necessary to eliminate soil completely in order to obtain the advantages of hydroponics, which is based on an increase in the amount of water and nutrients per unit volume of culture medium.

A one- to three-inch layer of soil, supported about one inch above water, held in a basin, and given the common fertilizer treatments of agriculture, will provide crops with needed plant food and water. By separating the zone of the material that

provides the nutrients from that which provides the water, the available water content per cubic foot area is increased about three times. A cube foot sector of average land, exposing one square foot to sunlight, would have less than three inches of available water, compared to eight inches under the three-inch layer of soil, and more if a shallower seedbed is used.

Fig. 56. Bed of loam soil planted to lawn grass, supported in basins with nutrient solution below.

Enough roots must enter the water to absorb sufficient moisture for the crops. Also the seedbed must be kept sufficiently moist to encourage root growth. Once the roots are established in the solution, the seedbed naturally will be kept moist by capillarity. However, the roots of crops such as lettuce, spinach, and many flowers, planted in a three-inch layer of soil, cannot penetrate into the water below. Shallow-rooted plants should

be planted in a shallower seedbed. Strong-rooted crops like roses, gardenias, corn, and dahlias will establish a root system in the water.

The relationship between yields and the amount of fertilizer applied to land is influenced by fixation of plant food by the soil, which renders it unavailable.

As we proceed from pure water to the various kinds of ground water and the various kinds of porous solids with which water comes in contact, we have a progressive series of nutrient fixing and precipitating agencies. The liquid which filters out of a layer of soil from a nutrient solution poured on it has different proportions of the elements that it originally contained because some of the elements have become fixed by the solid particles. Fertilizers applied to land bear generally no relation to the composition of the crops. The science of their application is merely that of providing plant food, because whatever combination based on composition might be made would be nullified by the properties of the soil. In soils of less fixing power, such as sands, cinders, or gravels, combinations or formulas have some importance. In hydroponics, with no fixing power, combinations have the greatest importance.

CHAPTER TWENTY-ONE

Hydroponics and Agriculture

HYDROPONICS is agriculture's first real competitor. It can outyield soil production in a number of crops and can produce crops in regions of good climate where lack of fertile soil or adequate water prevents the practice of agriculture.

The average yield of important crops per acre of farm land varies from one-tenth to one-fourth of the possible maximum yield. For example, the highest yields of wheat, potatoes, and rice per acre in the United States in round numbers are, respectively, 120 and 1,150 and 170 bushels. Averages for these crops are 17, 120, and 35 bushels respectively. By hydroponics, the average yield per acre of tank space can be maintained at close to the maximum potentiality. In other words, from four to ten times the average yield from an acre of soil can be obtained. This is because water and plant food can always be made available in the amounts needed.

Furthermore, a cubic foot of nutrient solution weighing 62.5 pounds provides about six times the amount of water and nutrients contained by the solution in a cubic foot of soil. For this reason, plants can be grown closer together than in agriculture.

The water requirement of plants (that is, the amount of water needed to produce a certain gain in dry weight) is generally smaller in hydroponics, partly because of the denser stand of vegetation which maintains higher humidity in the air surrounding the plants and thus cuts down on transpiration of

water from leaf surfaces. The fact that the litter seedbed loses less water by evaporation than does the soil also bears on this point. And, finally, all the water supplied in hydroponics is available to the plants; this is not the case in agriculture.

The statements above may have to be modified, however, when plants are exposed to dry winds. In this case loss of water by transpiration is greater because of the free state of the water in the basin. Loss is greater in a small basin than in a large one, for a larger proportion of the surface is exposed to the winds because of relatively greater border.

Food Requirement of Plants

The plant-food requirement is also lower in hydroponics than in agriculture because full use is made of all the nutrients provided. In soil production a considerable part of the fertilizer applied is lost through leaching or by reacting with the earth to form insoluble compounds.

Plants grown in nutrient solution can be forced to absorb a larger amount of certain mineral elements than if they are grown in soil. It is therefore possible to control plant composition. In time we may use this method to produce crops with unique mineral composition and dietary value. In such cases the food requirements might be higher than in agriculture.

Carbon Dioxide

Marked increases in the density of the stand of vegetation in hydroponics bring up the question of carbon dioxide supply. This important gas is obtained from the air and from the soil, where it is produced by chemical and biological reactions. It is conceivable that, as hydroponic fields grow in size, the free flow of air may be impeded. And, when plants are grown in greenhouses with impervious floors, the diffusion from the soil may be cut off. In one of the commercial hydroponicums now operating, such a difficulty was anticipated, and additional carbon dioxide was supplied by a regulated discharge of sulfuric acid on limestone. There was no evidence of benefit from the

carbon dioxide, so it was assumed that the plants were receiving an adequate supply by natural means in this case.

Production of Cereals

Experiments have not yet been conducted to determine the suitability of hydroponics for production of cereal grains. From a physiological standpoint cereals are ideal, but their food requirements are very high. The cost of chemicals alone would exceed the value of the crop at present low prices. The possibility of using nitrogen-fixing bacteria in hydroponic technique to gather nitrogen from the air might conceivably lower the cost of production of cereals by water culture.

Comparison of Labor Cost

No statistical data on labor cost per unit area in h
are now available. They can be obtained only after the experimental phase of the science has been completed and it has been established on a sound commercial basis. Nevertheless, some comparisons of probable labor cost in hydroponics and agriculture can be made.

Tillage machinery is not needed in hydroponics, but it is the backbone of agricultural production. Wheat and rye are predominantly machine-harvested but, as pointed out above, cereal grains cannot be produced economically by hydroponics. A large majority of the other principal food crops of the world are still harvested by hand. Thus, comparison of the labor cost involved in harvesting them resolves itself into an analysis of manual effort and movement. Let us consider corn and potatoes, two of the most widely distributed food plants.

In all large potato fields the tubers are dug by machinery which scatters them over the surface. Although some growers now have bagging appliances, over most acreage the potatoes must then be picked up by hand. The average picker handles about 140 bushels a day on land of better than average production. The manual effort involved in harvesting the tubers from hydroponic basins will be substantially less.

Corn picking involves a different type of manual movement. The champion corn picker finds even rows of corn in the field much easier to handle by his machine-like method. But, for the average person whose technique is less specialized, the closer stands in hydroponics will present no inconvenience.

Sociological Implications

The increase in agricultural production per manpower through the use of machinery has resulted in a centralized system of farm economy and management. The capital investment in operating equipment is very large for the value of the crop grown. Many farmers spend most of their income on machinery and mechanical equipment. Thus, economy of production depends upon mass production and the farming of large acreages. The trend is toward corporate agriculture.

Hydroponics dispenses with machinery and obtains mass production without centralized control. A small farm unit can be operated as efficiently as a large one. Hence, the small grower will no longer be at a disadvantage in the competition for economical production.

Reclamation projects in some arid regions have stored an abundance of water that, if used for hydroponics, could support populations many times greater than exist today. It is quite likely that soilless crop production will initiate and direct new currents of migration into such regions.

Every man who tills the soil in this country supports, whether he wants to or not, two other people living in urban communities, as shown by the last census. When some of these are unemployed, as millions have been during the last decade, they cannot buy their food but still must be fed.

One way of lightening the burden of relief expenditures is to alter the ratio of agricultural to non-agricultural laborers. The unemployed must become farmers themselves, and produce their own subsistence. Many will now ask, "Where are these people to get farms? The good land is taken already." The answer lies in hydroponics, which can operate wherever climate is favorable and produce on a small plot the same amount of

food as can agriculture on a large farm. It offers the most feasible method of removing the unemployed from towns and cities where private employment for all of them may never again be available and of allowing them to support themselves at lower cost to the national community.

Fig. 57. Potatoes and corn together. The potatoes are nine weeks after planting and five weeks after they were up. The corn is four weeks old.

Multiple Cropping

Dual and multiple cropping of plants in the same basin are the most recent and sensational developments in hydroponics. Experiments have shown that they are entirely feasible and foreshadow tremendous increases in yields per unit area for many crops. Two crops can be grown together in agriculture but only on a limited scale because of the difficulties of seeding, cultivating, and harvesting mixed vegetation, and because of the inability of the soil to provide the needed plant food. Multiple cropping, the practice of growing three and even four different crops together, is impossible in soil.

In inter-cropping, the practice of growing two crops together in agriculture, a plant with a short growing season is grown

with one having a long season. This is done in such a way that the growth of the latter is not inhibited. Its purpose is to increase the benefits gained from the months of favorable weather rather than to use accumulated fertility of the soil. Few soils increase in fertility as plants are grown in them, and then only when legumes are the crop produced. After the nutrient content of the soil has been reduced, seasons of fallow and rotation of crops are required to build it up once more. When crops are grown in nutrient solution, such considerations can be disregarded, for the supply of food in the solution can be so increased and replenished that one crop, regardless of how thickly it is seeded, cannot use it all.

Crops should be chosen whose vegetation will not compete for light in such a way that one plant is cut off from its supply by another. This brings up the question of leaf structure, for the amount of light available to each plant is measured by the leaf area exposed to the sun. It is only through adequate exposure that the plants can absorb the life-giving rays. Plant leaves are not uniform in shape and size. Nor do they all grow at an equal level. Thus a unit area cannot be covered by a solid and uniform layer of green material. As the plants grow, their light requirement increases. When they reach such a size that they begin to shade each other, the increase in utilization of light is no longer directly proportional to the increase in leaf surface. Therefore, multiple cropping becomes a method of arranging and seeding the plants in such a way and at such different times that, when one has passed its period of full light requirement, another is just entering that stage, for only when the entire area is covered with light-absorbing foliage can the maximum yield be realized. As soon as one crop's vegetation becomes inactive through age, another should take its place. Very little time should elapse between the period in which one plant stops absorbing light and another grows up to take its place. To maintain this relationship, cultural technique should be designed to keep some plants short and sturdy, for very tall plants interfere with absorption of light by the others.

The species grown together should have similar climatic and nutritional requirements but be different in structure. This

makes it possible to grow them under the same conditions and at the same time dovetail them in such a way that each receives its proper amount of light. Most of the cereals are too similar in structure to be grown in this way. For example, spring wheat and barley maintain parallel height during their growth. Thus, there is no advantage in sowing them together, since the dense stand needed for maximum utilization of plant food can be obtained simply by sowing either one more thickly alone.

Potatoes and Corn

As examples of crops which can be grown together with good results, we may take potatoes and corn: one a short crop and the other a tall one. They have wide regional distribution and may be grown under the same conditions in many parts of the world. That is, they can be grown together in hydroponics, not in agriculture.

The potato is a cool-weather crop; corn is a warm-weather crop. Four to six weeks are needed for potatoes to appear above the surface, and seven to ten days for corn. In areas of the United States where these crops are grown extensively, potatoes are planted in the latter part of March or the first part of April, while corn is planted in the latter part of April or the beginning of May. The time of planting is very important, for one must not be allowed to reach such a size that it shades the other during early growth. This makes it impossible to plant corn and potatoes at the same time. For in cool weather the potatoes would shoot ahead and overshadow the young corn. In hot weather the situation would be just the reverse. Consequently, the potatoes must be planted in cool weather and the corn later when it is warm. If the vegetation of both can be maintained at approximately the same level for from eight to ten weeks, they can be produced together successfully. The length of time during which they must be kept at the same level varies with varieties, character of the climate, and, in the case of potatoes, age of the seed. Hot weather shortens the growing period of potatoes relatively more than cool weather lengthens that of corn.

The leaf structure of potatoes and corn is ideal for making the maximum use of the light supplied by the sun. Corn has long, drooping leaves, spaced far apart. Potatoes have a compact foliage, the leaves being short, broad, and close together. Corn can extend several inches above the potatoes without interfering with their light supply. However, if the crops are planted close together, the corn should not be allowed to grow above the potatoes until after the tubers have started to form. The potato has its maximum light period at about the time the entire field is covered with foliage. Then three or four weeks more, depending upon the varieties used, are required before

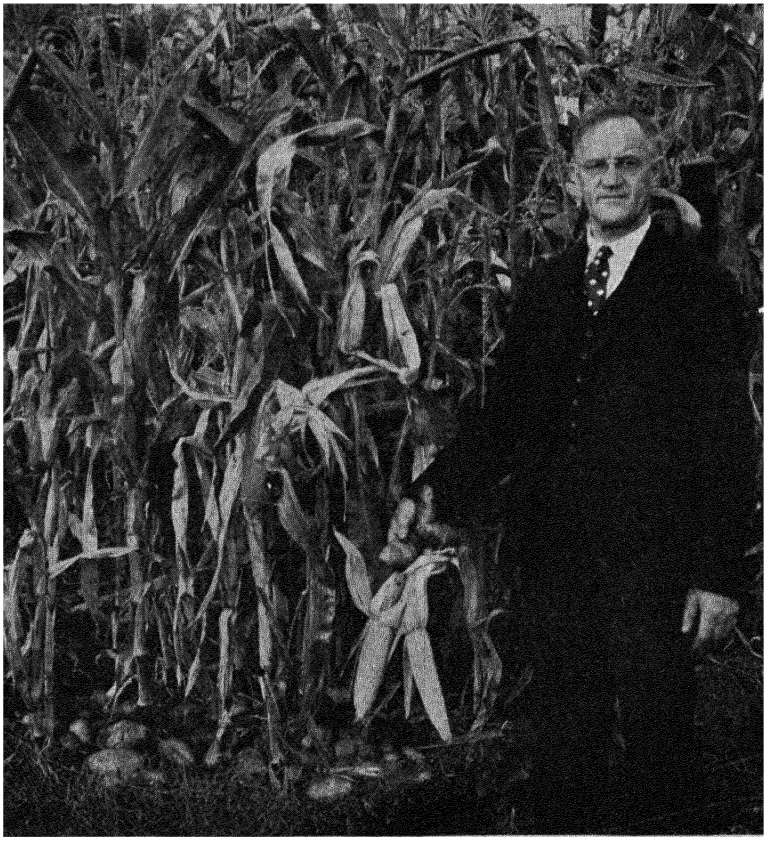

Fig. 58. Corn and potatoes in figure 57 ready for harvest.

the crop becomes so matured that all of the direct light is no longer required. After that time corn may be allowed to shade the field, for the tubers will develop to maturity in diffused light.

The nutritional requirements of these plants are not markedly different. They can be cared for by simple supplementation of the supply of certain elements in the solution. But the rooting properties are quite different. Potatoes, because of their abundance of fine lateral roots, have greater absorbing power than the corn, whose roots are thick and penetrate deeply into the solution. If the two crops were to compete for a limited supply of nutrients in the soil or in a shallow basin, the potatoes might operate to the detriment of the corn. On the other hand, corn should win out in a basin of greater depth. Fortunately, these two crops need not compete for food in hydroponics, for an ample supply for both can be maintained even in a shallow basin.

Potatoes and Tomatoes

Potatoes and tomatoes can also be grown together with very satisfactory results. They are much alike in shape and size of foliage, and under natural conditions would compete with each other for light. However, the tomatoes can be pruned of lateral branches so that they grow upward above the potatoes. Then each can be planted closer together than in agriculture. Like corn, the tomato is a warm-weather crop, and seedlings from four to six inches high can be planted with potatoes just as the latter are appearing above the surface. The tomatoes should then be held just a few inches above the potatoes for about eight weeks. Since the potato matures more quickly than the tomato, it will then have entered its period of maximum light requirement. The tomato may now be allowed to grow as it pleases. Several weeks will be required before it can shut off light from the potato and by that time the latter will have passed the period when it needs direct sunlight.

In many regions the climate is such that certain vegetable crops can be sown in the litter seedbed before the potatoes are

planted. When the time comes to plant the latter, their seed can be inserted in the litter among the growing plants. Planting may offer some difficulty but can be made sufficiently effective to insure thick stands and high yields. It is unnecessary to harvest such crops as onions to make room for the potatoes. The tubers will develop above or among them in the litter and be protected from the sunlight. As explained in the foregoing paragraphs, corn and tomatoes may then be planted in the same basin.

Experimental Yields

The productive capacity of multiple cropping is best illustrated by a description of experiments already completed in outdoor basins at Berkeley, California. They leave no doubt as to the potentialities of the method.

Four basins of potatoes were planted: one on March 1, the second on March 15, and the other two on April 1. Spacing was at the rate of one plant to 90 square inches in three of the basins and one to 144 square inches in the fourth. In agriculture potatoes are spaced one plant to about every 250 or 280 square inches in the highest-producing fields, and for the bulk of the acreage one plant to every 350 or 450 square inches. On April 10 tomatoes were planted in two of the basins. In the first basin planted, the potatoes were then about two inches high. In the second they were just appearing. The tomato plants were six inches tall and spaced at about one to every three square feet. On May 5 corn was planted, spaced about four times as close together as in agriculture, in one of the basins seeded to potatoes on April 1. The remaining basin was planted to potatoes about six weeks after the first planting of this crop had appeared above the surface. This was estimated to be ten weeks before the maturity of the first crop. The object was to superimpose another crop on the first and harvest them together.

The basins were each 1/220 of an acre in area. The yield of corn and potatoes together was 6.8 bushels, or 408 pounds, of potatoes and 1.11 bushels, or 78 pounds, of corn. The yield of potatoes and tomatoes was 8.6 bushels of potatoes and a little

more than 1,000 pounds of tomatoes. The tomatoes in this case were Sutton's Best. The other varieties tested did not respond to the cultural technique. The second crop of potatoes also failed, but it was discovered that this was due to their having been planted too early. A second experiment was carried out with the second crop planted later, and results were very good.

Fig. 59. A potato, tomato, and celery combination, planted in a concrete basin 6 by 36 feet. The potato vines have begun to break down. The tubers are nearly full-grown. The tomato plants are about 5 feet tall and are bearing fruit. The celery has recently been planted.

On July 15 the basin carrying the record production of potatoes and tomatoes was also planted to 200 celery seedlings. Spacing of these plants was about three times as close as in field planting. The potatoes by this time had passed their period of full light requirement and the tomatoes were about three feet tall. By keeping the tomatoes pruned it was possible to grow a good crop of celery.

In all these experiments conditions of culture were approxi-

mately the same as those that will prevail when larger areas are planted, and thus it was feasible to compute the yield on an acre basis for comparison with agriculture.

Finally, in another experiment corn, beans, and potatoes have been grown together in the same basin. All of them have produced good yields.

Multiple Cropping of Flowers

Multiple cropping is well-adapted for use in growing flowers for either decorative or commercial purposes. By correct choice of species it is possible to have at least one crop flowering in the basins as long as climate will permit. A possible cropping program might run like this: plant Holland bulbs first; several weeks before they are blooming, plant gladioli; several weeks before the gladioli bloom, plant flowers having greater leaf surface, such as marigolds, dahlias, or snap-dragons. Since flowers have a wide range of characteristics, many good combinations can be worked out.

Use of Chemicals

Multiple cropping offers the final proof that different plant species do not necessarily require different chemical formulas. As I have explained, the chemical formula is based upon the plant's composition. But tomatoes, corn, and potatoes which are grown together successfully all have markedly different composition at maturity. This may be paradoxical, but the explanation is simple. The plant's actual mineral requirement is determined by the composition of those plant parts which manufacture the products for which it is grown. The sugar in cane, the starch in potato, the starch and protein in wheat: all these are storage products. When they are subtracted from the total components of the plant, we arrive at the composition and structure of the factory which produces them. This basic composition does not vary appreciably between species.

Probably the most efficient use of water and nutrients occurs when different species are grown together. This is in accord-

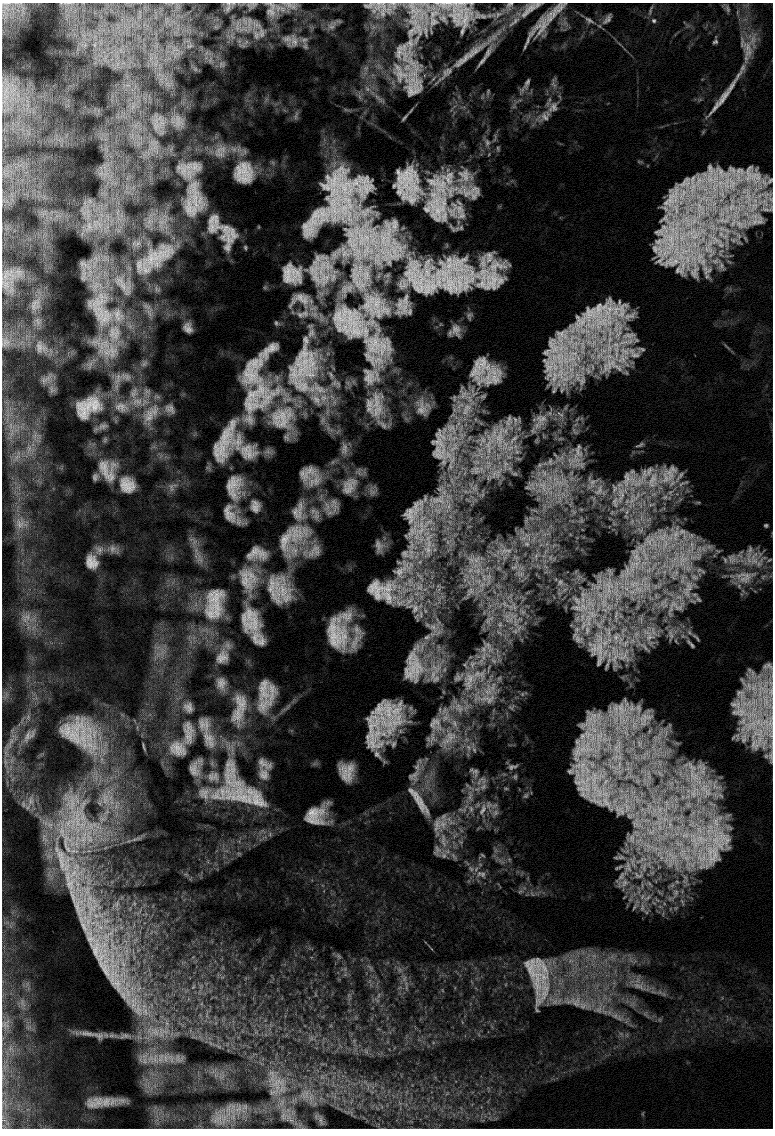

Fig. 60. Multiple cropping—a bed of daffodils, godetias, gladioli, and chrysanthemums, which were the last to bloom.

ance with Nature, for natural vegetative cover is multifloral. Weeds and corn growing together in a field extract more water and food from the soil than does corn alone. In hydroponics we obtain such diverse vegetation by growing useful species together and thus bringing about that competition for food and water which is the basis of economy.

Economic Possibilities

Multiple cropping also answers the criticism that equipment cost makes it economically impossible for hydroponics to compete with agriculture in some fields. It is true, for example, that the cost of the basins prevents us from growing corn alone and selling it at the same price that it brings in agriculture. Even the increased yields cannot overcome the greater initial expense of operation. But, when potatoes are grown with the corn and allowed to bear the cost of equipment, then the grain is left free to compete with soil-grown corn on the basis of the cost of chemicals. Under such conditions hydroponics can compete very successfully with agriculture.

Glossary

absorption—process of intake, by plants, of water and materials in solution; also process of removal of materials from solution by soils (adsorption).

acidity—amount of hydrogen ion in solution (sourness).

acid-alkaline reaction—range from acid to alkaline conditions.

agriculture—culture of the field; applies to conditions of plant culture where nutrients are provided in a liquid film around solid particles.

alkali—material that gives off hydroxyl ions or basic properties.

annual—a crop that lasts one season, reproducing itself each year from seed.

atmosphere—the air surrounding the earth; its pressure at sea level is 14.7 pounds per square inch; raises water in a vacuum 33.9 feet, mercury 760 millimeters.

basin—shallow container of water; flat tank.

biennial—a plant requiring two years to produce seed.

blanching—loss of green pigment (chlorophyll) in plants.

broadcast seeding—seeds sown by scattering, not in rows.

budding—a method of grafting with a bud instead of a small shoot or scion.

capillarity—the action by which the surface of a liquid and solids are attracted; the force depends on attraction of molecules.

carbohydrate—a chemical compound of carbon, hydrogen, and oxygen in which the ratio of hydrogen to oxygen is the same as in water.

Centigrade—temperature scale giving freezing of water at 0°, boiling at 100°; one degree Centigrade equals 1.8 degrees Fahrenheit.

chlorophyll—the green coloring matter in plants.

climate—the complex of light, temperature, wind, rain, and atmosphere pertaining to definite regions.

complementary relation—for a given degree of acidity, a corresponding degree of alkalinity.

compound—a distinct substance formed by the union of two or more distinct substances; i.e., two distinct gases, hydrogen and oxygen, unite to form a new substance, water.

concentration—the quantities of any material in a unit quantity of water, gas, or other substance.

conducting roots—roots that act merely as vessels or tubes through which a solution passes.

deciduous—perennial plants that lose their leaves annually.

density—(as applied to planting) the number of plants or seeds to a unit of area.

dormancy—a state of rest, so far as vegetative growth is concerned.

drowning—death caused when air required for respiration is cut out by water.

dry weight—the weight of a plant or other material minus the water in it.

ecology—response of the plant to its environment; a study of the reaction of plants to outside influences.

electric dissociation—the processes whereby some molecules break down into the smaller chemical units, the ions.

element—one of the 92 distinct forms of matter of which all other substances are composed: i.e., iron, oxygen, hydrogen.

embryo flower—the young flower within the bulb, seed or plant.

ensilage—corn or other plants stored green in a silo as fodder for live stock.

Fahrenheit—the temperature scale which gives freezing of water at 32° and boiling at 212°; one degree Fahrenheit is 5/9 of a degree in Centigrade.

fermentation—the chemical and biological process by which organic materials are broken down by bacteria or other agents.

feeding roots—the new roots which have the capacity to absorb nutrients.

fibrous roots—thin hair-like roots that grow from the root crown or from large roots.

filtration—penetration by percolation; the process of passing through fine interstices.

forcing crops—crops grown by heating soil, solution, or air.

germination—the sprouting of seeds; first evidence of growth.

gradient—change by steps in the character of a line, such as change in elevation of a road up a mountain; differences in heat as one approaches a hot stove.

graft—propagation by insertion of a bud or scion in a rooted plant.

hard water—water that contains bicarbonate of calcium or magnesium, distinctive from that containing the carbonate or bicarbonate of sodium.

heritable properties—characters transmitted from parent to offspring through germ cells.

hybrid—the offspring of the union of different races or species. In horticulture, applied to a union of two species of the same class. "Cross-breed" is usually applied to a union of species to which there is conventional objection.

hydroponics—a new word. The art and science of crop production in liquid culture media.

hydroponicist—one who grows crops by hydroponics.

hydroponicum—the farm, garden, or place where crops are grown by hydroponics.

ignition loss—the loss in weight of dry material by combustion heating.

indicator—chemical used to determine the acidity or alkalinity of solutions.

inter-cropping—growing two crops together in agriculture.

inorganic—(chemicals) not containing carbon compounds as a nucleus.

insoluble—not soluble in water.

ion—a part of the molecule which carries electricity when it dissociates.

liter—a measure of volume containing 1,000 cubic centimeters; 1.0567 U.S. liquid quarts or .88 British imperial quart.

litter—straw, hay, leaves, or any vegetable matter used as bedding.

mosaic—applied to the mottled appearance of leaves of plants due to a disease usually carried by insects.

molecular concentration—(of solutions) the quantity of dissolved substances expressed by molecules per unit of volume.

multiple cropping—(a new term) the growing of two or more crops together by hydroponics to obtain greater use of light per unit area of space.

nutrient—food; used in this book for both mineral and organic materials essential for plant growth.

nutrient solution—a solution containing the chemical elements necessary for plant growth in proper form and concentration.

organic decomposition—decay or disintegration of plant and animal materials.

osmosis—a type of diffusion of liquids—applied particularly to passage of substances through porous membranes causing changes in the concentrations on either side.

osmotic pressure—the measure of the pressure or force caused by osmosis.

perennial—plants that continue to grow more than two years.

permeable membrane—a membrane that permits materials to pass through.

*p*H *scale*—a system used to measure degrees of acidity and alkalinity.

physiology—the science of the chemistry and physics of living matter.

photosynthesis—the process by which plants, under the influence of light, manufacture products—most commonly applied to the building of carbohydrates from carbon-dioxide and water by chlorophyll under the action of sunlight.

plant food—the elements in the nutrient solution. Also materials in the plants later needed in growth.

pollination—the process of introducing pollen into the seed cells; also known as *fertilization.*

P. P. M.—parts per million.

protein—chemical compounds of plants and animals built up from simpler nitrogen compounds (amino acids). Percent of nitrogen multiplied by 5.7 for wheat, and 6.25 for other products, gives the amount of protein.

precipitate—insoluble compounds formed by chemical reactions—usually applied to materials thrown out of solutions.

reaction—acid or alkaline state of solutions.

respiration—breathing—taking in air and giving off carbon dioxide; also, giving off carbon dioxide without taking in air.

root crown—the junction between stalk and fine roots—the crotch where roots are joined.

root stock—the stock on which buds or scions are grafted.

root-top ratio—the ratio of weight or length of roots to the weight of stalks and leaves.

root zone—the stratum in which roots grow.

salinity—amount of inorganic materials in solution in natural water.

salt molecule—the molecule of any of the chemical plant foods added to the water.

selective absorption—differences in rate of intake of elements by plants, giving rise to an apparent preference for some in respect to others.

sets—young rooted plants, or bulbs, for transplanting.

scion—a bud or shoot for propagation by grafting.

soft water—water free from bicarbonates of calcium and magnesium—lathers easily.

soil—the solid, porous foundation of earth materials which supports plants.

soil solution—the film of liquid around soil particles.

solute—a substance dissolved in liquid.

solvent—the liquid in which a substance is dissolved.

storage root—enlarged root containing materials manufactured in the leaves.

suckers—new shoots or tillers arising from the buds at the base of the plant.

synthesis—the process of building up compounds from simpler ones.

tap root—main vertical root.

technique—method of operation or mechanical performance.

tillers—suckers or shoots arising from buds at the base of a plant; most commonly applied to plants of the grass family, such as cereals.

toxic—poisonous.

total solids—weight of materials, such as plant products, when all water has been removed. Residue remaining from solution when all water is removed.

trace elements—elements present in small quantities.

transpiration—loss of water, usually as vapor, from leaves and stem.

vegetable litter—litter from plants.

virus—a transmittable poison of animal or plant origin.

water culture—original name applied to the growing of plants in nutrient solutions for experimental study.

weather—state of atmosphere in respect to heat or cold, dryness or wetness, wind, etc.

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