AUTOMATICALLY OPERATED SAND-CULTURE EQUIPMENT[1]

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INTRODUCTION

There are described in this paper the principles of an automatically operated sand-culture equipment. This equipment is designed to provide (1) the advantages of large-vessel, or flowing-type, water cultures with regard to the maintenance of solution concentration, and (2) the numerous advantages of sand cultures, such as aeration, iron supply, seedling germination, root environment, and elimination of plant supports.

Students of plant nutrition have relied for a good many years on the use of artificially prepared solutions for the development of information on the essential character and toxicity of the salt constituents of the soil solution. In investigations of purely qualitative character, specialized equipment has been largely uncalled for, but in many directions inquiries of this type have now progressed into quantitative fields; accordingly, it has become increasingly important that the methods employed be such that the concentrations of ions presented to plant roots can be maintained within closely fixed limits.

Briefly stated, with the equipment here described the solution is applied by automatically controlled pumps to the surface of free-draining sand cultures at hourly or other selected intervals. The displaced solution returns by gravity to the supply reservoir. Since the capacity of this reservoir is large as compared with the volume of the solution held by the sand, the maintenance of solution concentrations within reasonable limits resolves itself into a matter of periodic replenishment of the water and salt constituents that are removed by the plants. The frequent automatic replacement of the solution held by the sand prevents any noteworthy changes in the concentrations of elements presented to the plant roots. New solutions are recurrently substituted for those in use. Iron is supplied in the form of water-insoluble minerals mixed with the sand. The present paper gives a detailed description of the construction and operation of this widely adaptable sand-culture principle.

DESCRIPTION

GENERAL

A unit of sand-culture equipment comprises a sand culture, a solution reservoir, and a motor pump. Whether small, as for single plants or seedlings in the greenhouse, or large, as for trees carried into the fruiting stage, the sand cultures are always free-draining. The capacity of the solution reservoir should be large as compared with the daily transpiration demands of the plants. The reservoir is set at a level below that of the sand culture. The solution, intermittently

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pumped from this reservoir, is distributed over the top of the sand by suitably arranged perforated pipes, the rate of application being such that a sheet of free water is quickly developed. The volume per application, and therefore the duration of the run, is such that the solution residual from the previous application is displaced either wholly or partly, depending on the volume of the sand and the size of the plants. Drainage returns to the solution reservoir. The equipment is fully automatic. A time clock, with simple adjustments for frequency and duration of flooding, controls a magnetic switch that starts the pumps.

SAND BEDS AND RESERVOIRS

The method for maintaining solution concentrations is applicable to sand cultures of varied characteristics. The type or size of culture vessel depends on the particular experimental purpose served.

FIGURE 1.—Sand beds of galvanized iron. In each bed there are duplicate plantings of each of four crops in an experiment designed to determine the effect of high and low nitrate concentrations on the tolerance of each of these four kinds of plants to chloride and sulphate salts.

The sand beds described in an earlier publication,[2] and here illustrated as figure 1, have now been equipped with motors, and larger solution reservoirs have been installed. These sand beds, six in number, have surface dimensions of 18 inches by 12 feet. They are 11 inches deep at the sides and 13 inches deep along the center line. The bottom 2 inches of the beds (from the center line) is filled with pea gravel, and above this is placed a ¾-inch layer of coarse sand. The beds are then filled to within 1½ inches of the top with quartz sand. A ¼-inch-mesh screen separates the quartz sand from the coarse drainage sand so that the latter will not be disturbed when the roots of plants are pulled out in harvesting. Beneath the tanks, along the center line, there is riveted and soldered a 2-inch drain roll.

[2] EATON, F. M. A LARGE SAND CULTURE APPARATUS. Soil Sci. 31: 235–241, illus. 1930.

Multiple perforations in the bottom of the sand bed permit drainage into this roll, which in turn drains through a 1-inch pipe to the supply reservoir. A 2-inch overflow pipe connected to the drain roll opens about 1 inch above the surface of the sand. Evaporation and the

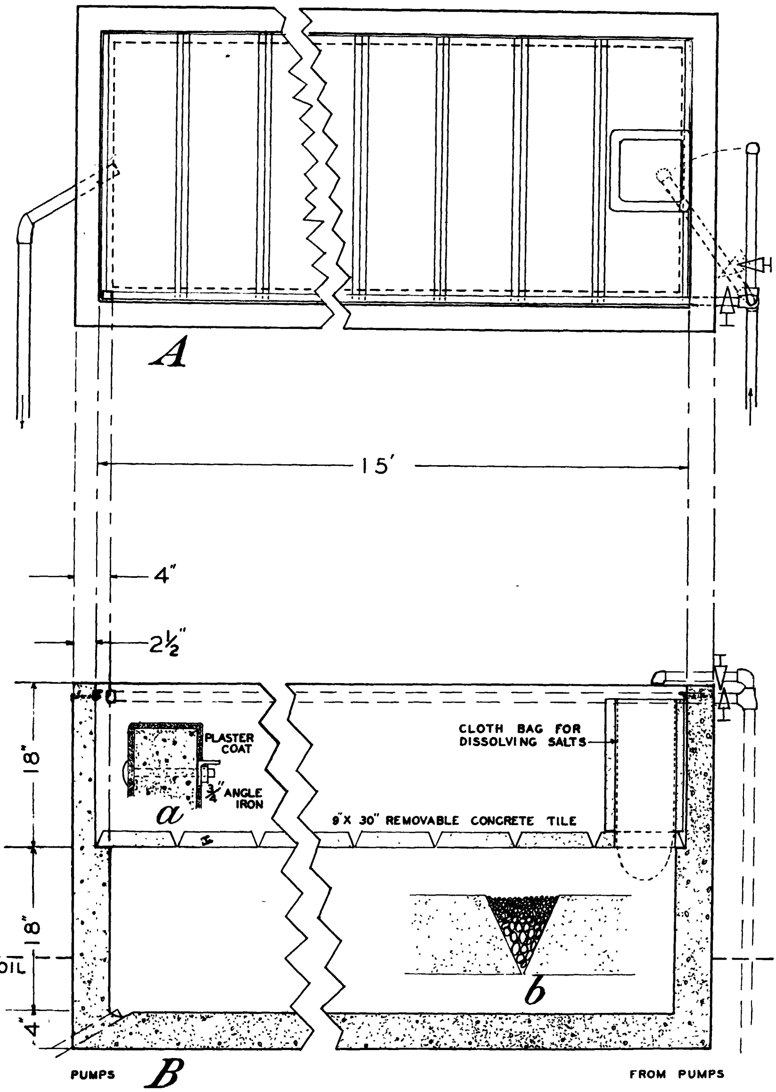

FIGURE 2.—Sections of shallow concrete sand beds to be used for annual crops: *A*, Horizontal section; *B*, vertical section. *a*, Reinforcing angle iron (welded at four corners), which supports perforated metal plates above sand, to suppress evaporation and the growth of algae; *b*, a section at edges of two cross tiles, showing the sand-and-gravel drainage way.

growth of algae are restricted in these beds by perforated galvanized plates supported a little above the surface of the sand. These plates, 12 by 18 inches, are used in pairs that overlap between the rows of plants, the edges next to the plants being turned up about one-half inch to prevent injury to the plant stems.

The sand cultures just described are to be replaced with new equipment of larger dimensions having certain advantages in design. The new cultures (fig. 2), are to be constructed of concrete, with each sand bed and its reservoir poured as a combined unit. The inside surface of the sand beds will be 30 inches wide and 15 feet long, and the depth of the sand will be 13.5 inches. The sand is to be supported above the solution by concrete tile resting on ledges. Each of the reservoirs is to have a capacity of 1,469 liters. The sand, extending to within 2½ inches of the top of the bed, will have a volume of 42.5 cubic feet, or 1, 204 cubic decimeters. Drainage from the sand to the reservoirs is effected through coarse sand and gravel placed between the beveled edges of the supporting tile. An earthen tile 7 inches square that extends from above the sand to an opening made in one of the end supporting tiles provides access to the reservoirs for measuring and renewing the culture solutions. Eight of these culture beds are to be constructed. The solution pumps, operated by belts from a shaft driven by a single motor, will be

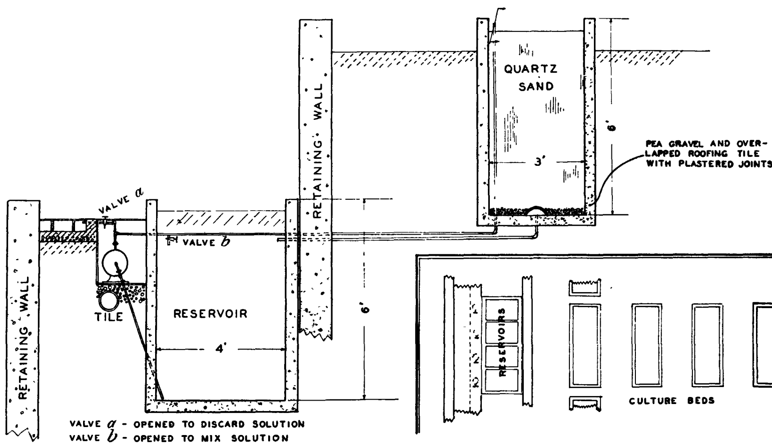

FIGURE 3.—Cross section of one of the deep sand beds with its supply reservoir. The insert shows the arrangement of four of these beds.

assembled in a suitable housing at one end of the experimental enclosure. The pumps, connected by 1¼-inch pipe with the reservoirs and sand-bed outlets, will have discharges of about 50 liters per minute. It is estimated that this complete equipment, exclusive of the culture sand, will cost about $1,000.

The culture vessels used at the Rubidoux Laboratory, Riverside, Calif., for trees (fig. 3) are constructed of concrete, the walls being 4 inches thick, the inside surface 3 by 10 feet, and the depth 6 feet. These beds, 20 in number, rise 1 foot above the ground and extend 5 feet into the ground. The supply reservoirs rise slightly above the surface of the ground on a lower terrace. A 1-inch layer of pea gravel, placed over the surface of permanent cultures of this type to check evaporation and algae growth, takes the place of the galvanized plates used on the metal sand beds where annual plants are grown.

Four sets of six 80-liter galvanized-metal containers are also in use. Each set of these cans has a common reservoir from which solution is withdrawn and to which the solution returns by free drainage. This equipment permits of four treatments with six different test crops under each.

It is to be recommended that the supply reservoirs for culture solutions be made large. Both water-retaining capacity of the sand and the expected daily volume loss by transpiration when plants are at full growth should be taken into account in planning for reservoir capacity.

Each of the shallow metal sand beds contains 382 cubic decimeters of sand and retains approximately 160 liters of solution against gravity, and each of the supply reservoirs holds 400 liters of solution, making a total of 560 liters of solution in each system. When plants are at full growth in the control bed, a day's transpiration loss in excess of 60 or 70 liters is regarded as high. If the absorption of salt constituents is neglected, then the concentration of the solution in the system would be increased in the order of 11 percent by 60 liters of transpiration. These supply reservoirs, accordingly, are regarded as being too small.

Per unit of sand surface, the reservoir capacity of the new shallow beds of concrete will be approximately double that of the shallow metal beds.

The capacity of each of the reservoirs of the large cultures for trees (fig. 3) is 1,600 liters. About 500 liters of solution is retained by the sand in each bed. Since the daily transpiration of 4-year-old trees grown in these beds will rarely exceed 100 liters, the daily concentration of the solution in the system will be increased by about 5 percent except possibly on occasional days when the saturation deficit is unusually high.

Rust-resistant galvanized metal will give many years of service if used above ground, particularly when a first coat of red-lead paint is applied inside. If properly protected outside by dressings of lead and asphalt, good underground service can be expected also; but such construction cannot be looked upon as permanent, and slow leakage is difficult to detect. When economy has been necessary, 50-gallon iron oil drums have been used; but these will last only a few years.

In connection with this description of metal beds, the comment may be made that there has been no evidence that plant injury has resulted from the use of red-lead paint applied as a first coat to protect the galvanized-metal surfaces from corrosion. Corn plants have been grown without injury in water cultures when a large mat of excelsior dipped in red-lead paint and dried, was inserted into the mason jars used as culture vessels. Plants were likewise uninjured when as much as 20 parts per million of lead as lead acetate was added to culture solutions. In the plumbing for sand-culture solutions with hydrogen-ion concentrations between pH 6 and 8, bronze and brass valves have been used freely without evidence of plant injury.

As a result of surface tension, the lower several inches of sand in cultures remains almost saturated with water after drainage has ceased; this effect, if regarded as undesirable, can be minimized by any one of a number of expedients.

PUMPS AND MOTORS

Several makes of centrifugal pumps with ½-inch outlets are in use, which will deliver solution at a rate of 20 liters per minute against a 6-foot head, when directly connected with motors of one-sixth horsepower and 1,450 revolutions per minute. A turbine pump, which has a somewhat higher efficiency, is also successfully employed. The centrifugal pumps used for the operation of the deep cultures illustrated in figure 3 are regarded as especially satisfactory. They have ½-inch outlets, and are connected with an induction-repulsion motor of one-fourth horsepower and 1,450 revolutions per minute. These pumps have a discharge of 20 liters per minute against a 20-foot head, and deliver in the order of 40 liters per minute through plumbing arranged as shown in figure 3. The discharge from each pump is carried through a ¾-inch pipe. None of the pumps in use are self-priming; accordingly, it has been the custom to mount them outside the reservoirs, about 15 inches below the normal level of the solution. In the work at Rubidoux Laboratory, solutions are returned to volume each day, and the loss in any one day is never sufficient to drain the pumps. The plumbing of each unit is so arranged that new culture solutions can be circulated for mixing before being applied to the beds.

Consideration has been given to the necessity for using pumps made of special alloys to prevent or reduce corrosion. The abrasion factor introduced by the sand is largely avoided by using care in establishing the coarse sand and gravel below the fine quartz sand. One manufacturer recommended, as satisfactory from the corrosion standpoint, a chrome-nickel-alloy steel, and pointed out that this metal, referred to as one of the 18–8 metals, would offer good resistance to abrasion, being comparable in this respect to cast steel. One of the centrifugal pumps has a cast-iron impeller and the others have bronze impellers; all have given satisfactory service during the first year of use, without material evidence of corrosion.

A sentinel-type breaker switch is installed adjacent to each motor pump, permitting independent operation and providing protection to the equipment.

The motor pumps, according to their type and the favorableness of the quotation, cost from $20 to $50 each, complete with base.

EQUIPMENT FOR AUTOMATIC OPERATION

The automatic operation of the motor pumps at the desired hours and for the desired durations may be effected in a number of ways. Two systems whereby the operation of the motors was limited by light-sensitive elements to the hours of substantial transpiration have been tried and discarded. Both proved to be subject to failure and required attention. The equipment described herein is now employed and is regarded as satisfactory. There is also described a simpler equipment that the writer believes might be suitable for many experimental purposes.

The equipment in use is comprised of (1) a time switch, (2) an auxiliary duration timer, (3) a small interposed auxiliary contactor, (4) a 75-ampere triple-pole magnetic contactor, and (5) a selector switch to permit operation of equipment automatically from the timer or by hand.

(1) Time switch (G. E. type T–15 time switch).—This piece has an electric clock with a 24-hour dial. The dial carries a series of movable "on" and "off" riders which actuate a mercury-to-mercury switch. The riders may be set to operate the pump equipment at intervals of

1 hour or longer. The minimum period between an "on" and "off" rider is one-half hour.

(*2*) *Auxiliary timer* (G. E. type TSA–10 timer).—This piece controls the duration of each operation of the motor pumps. The timing element consists of a small synchronous motor. By means of an electromagnetic clutch, the motor drives a pointer across a scale graduated in minutes. An adjustable arm with contact points is set on the scale for the desired time interval of operation. When the moving arm reaches the adjustable arm the contacts are opened, and shut down the motor pumps. The contacts on the adjustable arm are normally closed and are rated to carry 1 ampere at 115 or 230 volts.

(*3*) *Interposed auxiliary contactor* (G. E. CR 2810–1265).—The contacts of this piece are normally open. Its use is necessitated by the fact that the main contacts of the auxiliary timer (2) are limited to 1 ampere, whereas the operating coil of the magnetic contactor (4) that controls the pump motors will take an operating-coil inrush current of considerably more than 1 ampere. The operating coil of this auxiliary contactor requires only a fraction of an ampere. The current passing though the contacts of the auxiliary timer (2) energizes the coil of this interposed contactor, closing its contacts and thereby completing the secondary circuit through the coil of the magnetic switch (4).

(*4*) *Seventy-five-ampere triple-pole magnetic contactor.*—This contactor will carry the load represented by upward to 30 motors of one-sixth horsepower each. Either 110- or 220-volt single-phase motors may be operated from this three-pole magnetic switch by connecting them across the appropriate lines. The 110-volt current is used in the operating coil and in pieces 1, 2, and 3.

(*5*) *Selector switch* (G. E. Type CR 2960–SY103A).—This switch is wired in with the other devices so that the automatic time equipment is inactive when the switch arm is in the "hand" position; when in the "automatic" position, operation of the pump motors is entirely dependent on the timing-control circuit, and when in the "off" position the motors are shut down and are not affected by the operation of the timing equipment. The piece may be dispensed with by installing a snap switch across the lines from the contacts of the interposed contactor (3) to the magnetic contactor (4). Either arrangement permits one to run the motors independently of the timing device when solutions are to be mixed or the reservoirs emptied.

The external wiring diagram for connecting these pieces is simple and can be readily sketched by a manufacturer's representative. The external sketch, however, has little meaning except in conjunction with a study of the internal wiring diagrams of the several pieces which become somewhat complex and are not easily reproduced.

Briefly stated, one operation carries through as follows: An "on" rider on the time clock (1) closes the mercury-to-mercury switch and a 115-volt line current flows through the normally closed contacts of the auxiliary duration timer (2), the clock motor of which is started, and on through the coil of the normally open interposed auxiliary contactor (3). The contacts of the latter close, completing a second 115-volt circuit through the operating coil of the large 75-ampere magnetic switch (4), which contactor closes, starting the pumps. The pointer of the auxiliary timer (2) moves on by clock and separates its contacts at the end of the desired duration period. The breaking of this circuit deenergizes the coil of the interposed auxiliary contactor (3), allowing its contacts to open, which in turn breaks the circuit that has held the magnetic contactor (4) closed. The pumps are stopped at this point, but the cycle of the timing mechanism is not yet complete. When an "off" rider on the time switch (1) is reached, its mercury switch is opened. The opening of this switch automatically resets the auxiliary duration timer (2) for the next action.

The above control apparatus can be installed at a cost of about $100.

For some purposes the equipment for controlling pump operations may be greatly simplified by employing a time switch (G. E. type T–27) that has recently become available. As differing from the time switch (1), which has been described, an "off" rider of the newer type may be set to follow an "on" rider as closely as desired, but the minimum interval between "on" riders on the 24-hour dial is 1 hour and 45 minutes. The duration period cannot be adjusted as closely with these riders as it can be with the auxiliary timer described under (2). This timer employs, in place of the mercury-to-mercury switch, silver-button contacts capable of carrying a connected starting load of 40 amperes. A limited number of pump motors, accordingly, could be connected directly to the timer without accessory apparatus. Either with or without the magnetic switch, the time interval between operations can be reduced to 53 minutes by using two of these timers connected in parallel. The two timers, by appropriately setting the "on" riders, would alternate in operating the motor-pump or magnetic-switch circuits. The list price of this timer is about $20.

OPERATION

SELECTION OF SAND

Some importance is to be attached to the selection of quartz sand with particle sizes best suited to culture uses. If the sand is too coarse little water is held against gravity, whereas if the sand is too fine drainage is slow. Particularly undesirable is sand with particle sizes so mixed that little void remains when the sand has settled. Although this matter needs further study, it appears probable that no difficulty would be experienced with any sand held by a 100-mesh screen after passing a 40-mesh screen. A very satisfactory beach sand, taken at the foot of the Torrey Pines grade in southern California, had by weight 2 percent of 20–40-mesh particles, 25 percent of 40–60, 54 percent of 60–80, 13 percent of 80–100, and 6 percent of particles that passed a 100-mesh screen.

IRON SUPPLY

Experience at this laboratory has indicated that 0.1 percent of magnetite mixed with quartz sand makes unnecessary the use of soluble iron in the culture solutions maintained on the acid side of neutrality. A number of crop plants obtain sufficient iron from magnetite when the pH value is as high as 8. Pyrites may also be used as a source of iron if the medium is alkaline; on the acid side of neutrality, pyrites sometimes causes injury.[3] These data support the conclusion that iron may be obtained by plants from some water-

[3] Eaton, F. M., Blair, G. Y., and Wilcox, L. V. [Unpublished data.]

insoluble minerals by absorption across the particle-root interface, rather than by absorption from the culture or soil solution. The beach sand previously referred to in the present paper contains, in addition to constituents other than quartz, water-insoluble iron that is available to plants. Corn plants, which have a relatively high iron requirement, when grown in this sand showed no evidence of chlorosis if supplied with nutrient solutions maintained at pH values 5 to 6, 8, and 9.

CONTROL OF ORGANISMS

Free-living and pathogenic organisms tend to develop in sand cultures, particularly when the surface of the sand is not protected by gravel or metal plates to repress the growth of algae. Such an effect may become pronounced after several successive crops. It has, accordingly, become the writer's custom to apply a 0.5- to 1-percent solution of formaldehyde between crops. This solution is circulated by the pumps four or five times a day for several days, and is then washed out by several changes of water. The design of the equipment is such that steam or hot water can likewise be used for sterilization.

SALT ACCUMULATION AND DAMPING-OFF

Some minor evidence of accumulation of salts of low solubility on plant stems has been experienced when the concentrations of chlorides and sulphates have been made high in plant-tolerance studies. This has not been observed in the control beds, where only the usual nutrient solutions were used. The fact that solutions are applied at frequent intervals to a depth of 1 inch over the surface of the sand and then quickly drained away is doubtless largely responsible for general absence of salt incrustations. The lower portions of the stems, up which salt might creep from the sand, are submerged by each application of solution. The metal plates and gravel used to check algae growth serve likewise to reduce evaporation rates near the surface of the sand.

In the early seedling stages, when plants are most subject to damping-off, they transpire very little water. During this period root development is relatively rapid and it is not necessary to circulate the culture solutions, with the attendant wetting of the surface of the sand, since sufficient water and nutrients are supplied by the culture solution retained by the sand against drainage.

PRACTICAL SUGGESTIONS

USE OF SAND CULTURES IN HOTHOUSES

In a previous publication [4] the suggestion was offered that sand cultures might have practical advantages over soils in hothouse culture. Sand cultures are now being used commercially to a limited extent. In many cases plants supported by nutrient solutions in sand cultures have developed more rapidly and have been more fruitful than those grown in soils under otherwise similar conditions. Practical considerations incline the writer to the view that the usefulness of sand cultures is in no way limited to nutritional studies. The idea of maintaining the hydrogen-ion concentration and the concentrations and proportions of nutrients at levels best suited to the varied

[4] EATON, F. M. See footnote 2.

requirements of plants grown in hothouses is an inviting one, and there is likewise to be taken into account the ease with which soil organisms may be controlled.

Sand beds of the type shown in figure 2 are regarded as being well-adapted to greenhouse use. If judicious use is made of thermostats, culture temperatures may be closely controlled by installing steam pipes or electrical heating cable in the sand. The temperature of the culture solutions can likewise be controlled.

Plants may be removed from sand cultures for transplanting to the field or pots with a minimum of injury to the root systems.

COMPOSITION OF CULTURE SOLUTIONS

The following material on the composition of nutrient solutions will be wholly familiar to students of plant nutrition. It is offered for the convenience of those whose interests are primarily in the propagation and culture of plants.

Plants will make a creditable growth when supplied with culture solutions of markedly different composition. A highly satisfactory culture solution for some kinds of plants may be poorly suited to others, and a solution that is superior during one season of the year may not be the most desirable in another season, since climatic conditions, as well as length of day, influence the nutrition of plants. During recent years there has been a tendency toward the use of solutions that are less concentrated than many of those employed by the earlier investigators.

The composition of two culture solutions is shown in table 1. The first of these is a satisfactory and extensively used nutrient popularly known as Hoagland's solution. The second solution, is one that has been used effectively in nutritional studies in sand cultures at the Rubidoux Laboratory.

TABLE 1.—*Composition of 2 nutrient solutions*

Solution and constituents	Millimoles per liter	Grams per 100 liters
Hoagland's solution:		
Calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$	5	[1] 118 (91)
Potassium nitrate, KNO_3	5	51
Magnesium sulphate, $MgSO_4 \cdot 7H_2O$	2	49
Potassium acid phosphate, KH_2PO_4	1	14
A Rubidoux Laboratory solution:		
Calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$	4	[1] 94 (72)
Potassium nitrate, KNO_3	3	30
Ammonium sulphate $(NH_4)_2SO_4$	2	27
Magnesium sulphate, $MgSO_4 \cdot 7H_2O$	2	49
Potassium acid phosphate, KH_2PO_4	.2	3

[1] Weights in parentheses are for granular calcium nitrate with 15.5 percent nitrogen.

Iron must be made available to plants supported by nutrient solutions. Mention has been made of the suitability of certain water-insoluble iron minerals. Iron citrate can be added to culture solutions at the rate of 1 cc of a 0.5-percent solution per liter of nutrient each several days or sufficiently often to maintain the plants in good condition. Like amounts of specially prepared iron humate,[5] iron tartrate, or ferrous sulphate are also effective.

[5] HORNER, C. K., BURK, D., and HOOVER, S. R. PREPARATION OF HUMATE IRON AND OTHER HUMATE METALS. Plant Physiol. 9: 663–669. 1934.

In addition to iron and the elements of the base nutrient solution, plants require small amounts of certain other elements. Boron, manganese, and zinc should be introduced. For most purposes 1 p. p. m. of boron, 0.2 p. p. m. of manganese, and 0.1 p. p. m. of zinc will prove satisfactory. To approximate these concentrations in 100 liters of solution, add 0.6 g of boric acid (H_3BO_3), 0.1 g of manganese chloride ($MnCl_2.4H_2O$), and 0.04 g of zinc sulphate ($ZnSO_4.7H_2O$). It is not implied that other elements in small quantities are not beneficial, but the need of particular ones in addition to the amounts introduced as impurities with the principal salts has not yet been clearly defined. Many elements are contained in quartz sand, and they are likewise introduced if tap water is used in the preparation of solutions. So-called A-to-Z mixtures of miscellaneous elements, in very small amounts, are sometimes added to culture solutions, as are extracts of manure and soils.

The phosphate in culture solutions tends to precipitate the iron. Recent work by Olsen[6] shows further that absorbed iron may be precipitated and rendered inactive within the plant when the phosphate content of the nutrient is high. Hoagland's solution is often made up with only a tenth as much potassium phosphate as that given in the formula, and the phosphate content of the second solution is purposely made low for this reason.

For general-purpose culture solutions it is desirable to introduce a part of the nitrogen as ammonium ion. Unless tap water is used in making up the nutrient, 2 millimoles per liter of sodium chloride, NaCl (12 grams per 100 liters), should be added. The growth of some plants, tomatoes for example, will be substantially improved as a result of introducing this salt.

Tiedjens,[7] working with apples and tomatoes, has reported that nitrate ion was assimilated most satisfactorily when absorbed from an acid solution of approximately pH 4.0 whereas ammonium ion was assimilated most satisfactorily when absorbed from nutrient solutions having pH values of 5.0 to 6.5, varying somewhat with different varieties. In general, ammonium and nitrate salts produced equally good growth provided their limitations were recognized. Trelease and Trelease,[8] have proposed the use of solutions balanced with respect to NO_3/NH_4 ions to maintain stable hydrogen-ion concentrations.

If culture solutions are extensively employed, consideration can properly be given to the use of technical and commercial grades of chemicals, but some caution must be employed in their selection. The synthetic commercial fertilizers, such as ammonium sulphate and granular calcium nitrate, are usually relatively pure.

The frequency with which old solutions must be discarded and new ones substituted is always an individual problem, related, of course, to the volume of the supply and the size of the plants. Potassium, ammonium, and nitrate ions tend to become deficient in culture solutions more rapidly than some others. These and other constituents can be replaced as they are taken up by plants if laboratory facilities for their quantitative determination are available; otherwise it is desirable to substitute new solutions at frequent intervals.

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[6] OLSEN, C. IRON ABSORPTION AND CHLOROSIS IN GREEN PLANTS. Compt. Rend. Lab. Carlsberg, Sér. Chim. 21 (3): 15–52, illus. 1935.

[7] TIEDJENS, V. A. FACTORS AFFECTING ASSIMILATION OF AMMONIUM AND NITRATE ION, PARTICULARLY IN TOMATO AND APPLE. Plant Physiol. 9: 31–57, illus. 1934.

[8] TRELEASE, S. F., and TRELEASE, H. M. PHYSIOLOGICALLY BALANCED CULTURE SOLUTIONS WITH STABLE HYDROGEN-ION CONCENTRATION. Science (n. s.) 78: 438–439. 1933.

DISCUSSION

The electrical and mechanical features of the sand cultures here described have required little attention other than an occasional greasing and oiling of the pumps and motors. The unattended operation of the equipment on Saturday afternoons and Sundays has been entirely satisfactory. If much phosphate is used in culture solutions, it appears possible that calcium phosphate might accumulate in the pumps to such an extent that they would require cleaning.

The best quartz sand contains impurities that are not removed by digestion in strong acid, and for that reason water-culture technique is essential to some research. In water-culture technique practically all of the advantages are in favor of the large-vessel aerated type. Many workers have found flowing cultures inadequate as a means of maintaining uniform concentrations, except at the expense of wasting large volumes of solution, because the diverse conditions that exist between day and night and at the successive stages of plant development defy corresponding adjustments in the rate of supply of new solution. Problems concerned with seedling germination, aeration, iron supply, plant supports, and with less tangible matters attend the use of all forms of water culture. These difficulties are minimized in sand cultures, the use of which limits the care that must be devoted directly to plants during their growth to such operations as thinning, spraying for pests, and staking to prevent wind injury. The labor-saving advantages, however, may be regarded as somewhat incidental to the opportunity afforded, by the equipment here described, for closely controlling and defining the concentrations of solution constituents in sand cultures. In the majority of investigations, the traces of miscellaneous elements introduced by the quartz sand may be regarded as advantageous.

SUMMARY

The improved automatically operated sand-culture equipment described herein is designed to provide (1) the advantages of large-vessel, or flowing-type, water cultures with regard to the maintenance of solution concentration and (2) the numerous advantages of sand cultures, such as aeration, iron supply, seedling germination, root environment, and elimination of plant supports.

The solution is applied by motor pumps controlled by a time clock to the surface of free-draining sand cultures at hourly or other selected intervals. The displaced solution returns by gravity to the supply reservoir.

Equipment in use at the Rubidoux Laboratory is described, and suggestions are offered on the construction of sand beds and solution reservoirs, on types of sand, iron supply from water-insoluble minerals, control of troublesome organisms in the sand, and the applicability of the method to hothouse culture.

A brief account of the composition of certain culture solutions is given for the convenience of those interested in the propagation and culture of plants.