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SAND CULTURE OF SEEDLINGS

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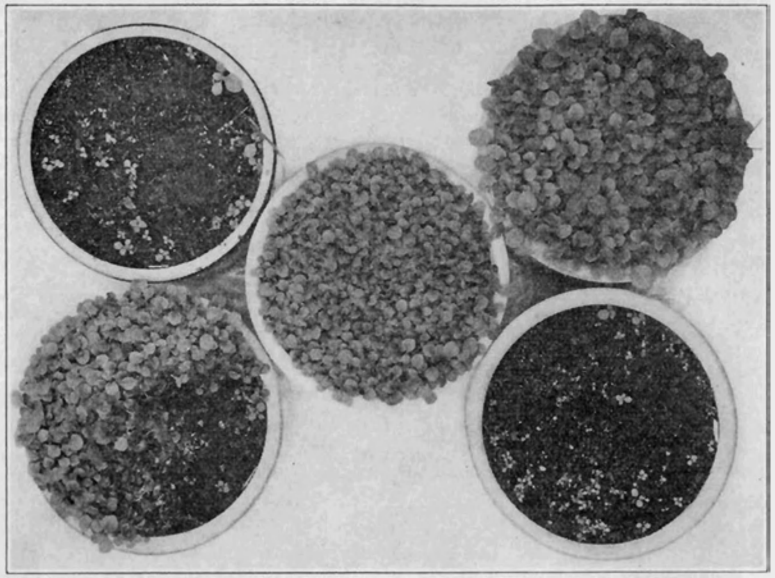


FIGURE 67. Tobacco seedlings. Left above, untreated soil; lower left, autoclaved soil; center, sand; upper right, formaldehyde dust in soil; lower right, red copper oxide on seed in untreated soil. In each crock approximately 4500 seeds were planted. The number of healthy seedlings in each crock at the end of 24 days was as follows: (1) 130, (2) 254, (3) 3955, (4) 1540, (5) 92.

FOREWORD

THE growing of seedlings in sand is a simple and inexpensive method which may be used advantageously under greenhouse conditions by vegetable growers, florists and nurserymen. Our experiments indicate that a larger number of healthy seedlings may be produced with less care by this method than by any soil methods now in use. It is a means of bringing the young plants safely through the early danger period when damping-off is likely to occur.

As compared with soil culture, the sand method produces seedlings that are more uniform in size, have stronger root systems, and whose growth may be more easily controlled. Although plants may develop to maturity in sand when nutrients are properly supplied, it is better to transplant them into soil when they reach a suitable size for handling.

Cleanliness is the important feature in this method. The sand must be washed *clean* with *hot* water each time before the seeds are planted.

Clean seed obtained from healthy plants requires no special treatment.

SAND CULTURE OF SEEDLINGS

A Method to Control Damping-Off

A. A. DUNLAP

INTRODUCTION

SEEDLINGS growing in soil are often destroyed in large numbers by soil-inhabiting fungi. These seedling diseases, usually known as damping-off, are especially common in the greenhouse and under seedbed conditions. To control the loss, many soil treatments have been devised and are now in use with varying degrees of effectiveness, but there is still need of improvement. Accordingly the sand culture of seedlings is being investigated, and in experiments conducted here this method has produced most readily the largest number of healthy plants from a given number of seeds.

Theoretically, washed sand is an ideal medium for the growth of disease-free seedlings. It contains practically no materials of an organic nature, that are necessary for fungus growth. Likewise the fertilizer salts added will not support the growth of fungi. Soil, on the other hand, usually contains large amounts of these organic substances, which are present in the sand only through the decay of seeds, dead rootlets, or through the growth of algae on the surface. Even sterilized soil retains its organic materials and fungi grow faster in such a medium, if recontamination takes place.

It has been known for some time that plants can be grown in pure sand provided certain food materials are properly added. Sand is also commonly used in the propagation of plants by cuttings. In this case the nutrients stored in the piece of plant stem are sufficient for the growth of new roots and to start new growth of shoot and leaf.

In attempts to avoid damping-off, growers have sometimes placed a layer of sand over soil after planting the seeds, to provide a fungus-free area near the soil line where the seedlings are often first attacked. Contact between sand and contaminated soil, however, makes this an uncertain method of control.

Owing to the variation among soils, scientists have frequently used sand or water cultures in studies of plant nutrition. In the course of such an investigation with the slow-growing rhododendron, Spencer and Shive (19) noticed that plants from seeds sown in quartz sand lacked certain diseases which were common among their soil-grown seedlings. They also mentioned that this method might have commercial possibilities. However, the use of sand for the growing of seedlings, with the direct purpose of avoiding damping-off, has apparently been first successfully accomplished at this Station.

RELATIVE VALUE OF SAND AND SOIL CULTURE

Before going into the details of the sand culture method, it is necessary to show the definite value of the procedure and to compare its effectiveness with the generally accepted soil treatments in the control of damping-off.

In this phase of the investigation, a large number of seedlings, most of which are highly susceptible to damping-off, and also representing various non-related families of plants, have been grown in both sand and soil cultures side by side in the same greenhouse. Experiments have been carried on under the changing temperature and light conditions as they exist at different seasons of the year. The containers used for both the sand and soil consisted of ordinary wooden flats and one-half gallon glazed crocks; other comparisons have been made in the open greenhouse bench. The soil used was a mixture of loam, leaf-mold, rotted manure and fine sand. Definite amounts of hydrated lime were added to some of the soil mixtures. Damping-off due to fungi of the genera *Rhizoctonia* and *Pythium* was common in the soil, the former being the chief cause among young seedlings, and the latter more frequently affecting older plants. Clinton (7) has reported that a large variety of economic plants in Connecticut are damped-off by these fungi under greenhouse conditions.

The exact details of the sand culture method are described later. Here it will suffice to say that the sand was washed in hot water and nutrients were added in the form of ordinary, inorganic fertilizers in solution, before the seeds were planted. Both sand and soil cultures were watered in the same manner with tap water, either by means of a hose or watering can. Both were kept thoroughly moist at all times to favor damping-off as well as to provide optimum conditions for rapid growth of seedlings.

The following soil cultures were used for comparison with the sand cultures: untreated soil, autoclaved soil, and soil treated with formaldehyde; also cuprous oxide powder (red copper oxide, Cu_2O) was used as a seed treatment in untreated soil. Several other compounds and methods were employed as trials but in our experiments those listed above were found to be most satisfactory for controlling damping-off in soil.

The autoclaved soil was more or less completely sterilized by heating for 2 hours at 10 to 15 pounds steam pressure. This treatment is comparable to thorough steam sterilizing as commonly practiced in greenhouses, or to electrical sterilization. Formaldehyde was used in varying strengths for soil treatment both as a dust, as recommended by Alexander, Young and Kiger (1) and in liquid form, as recommended by Guterman and Massey (10). In using the cuprous oxide for a *seed* treatment, the seeds were shaken with an excess of the powder, sifted free from any which did not adhere to their coats, and planted in plain, untreated soil.

The seeds used were obtained from seedsmen and were from regular commercial stocks. Except as indicated, no special treatment was applied to them either for soil or sand culture. In all cases except two, a definite number of seeds (by actual count) was placed in areas of comparable size in the sand and soil cultures. For tobacco and petunia, however, a definite volume of seeds containing an approximate number (counted once) was used. Both drilling and broadcasting of seeds were practiced.

After the first seedlings appeared, both sand and soil cultures were examined daily for the presence of damping-off. Each seedling thus affected was removed and a record was kept of the number destroyed. This procedure was followed until the seedlings had more than reached a suitable size for transplanting. Then the remainder was counted and the total of those damped-off for each culture was obtained.

TABLE 1* SEEDLING PRODUCTION IN SOIL AND SAND—EXPRESSED AS PERCENTAGE OF SEEDS PLANTED

SPECIES	SOIL				SAND
	Untreated	Cuprous Oxide on Seed	Formaldehyde Treated	Autoclaved	
Aster (China)	24	18	33	77	80
Beets	14	17	102**	108	116
Cabbage	45	62	83	85	91
Celery	29	67	75	65	92
Clarkia	9	6	18	31	53
Cosmos	2	11	48	55	64
Cucumber	35	40	87	84	92
Eggplant	16	11	70	69	72
Gypsophila	20	33	45	54	81
Lettuce	18	45	73	61	92
Onion	88	94	92	95	96
Pepper	55	41	86	76	84
Petunia	24	51	42	66	93
Pine (White)	8	12	8	25	45
Snapdragon	3	10	24	45	54
Spinach	17	15	30	63	56
Spruce (Red)	5	4	24	49	70
Sweet Corn	44	35	86	90	90
Sweet Pea	16	73	85	88	92
Tobacco	13	10	63	67	85
Tomato	64	91	87	83	94
Zinnia	20	29	72	72	82

* This and the next table include certain data previously given in a paper entitled "Seedling Culture in Sand to Prevent Damping-off", about to appear in *Phytopathology*.

** Percentages of over 100 are due to the presence of more than one embryo in the seed.

Table 1 compares the results of a large number (10 to 20 in case of each species) of sand and soil cultures which have been grown over a period of three years. It may be seen that, almost without exception, more seedlings, on the average, have been produced in the sand than in any of the soil cultures. In the case of certain vigorous seedlings such as corn, the results in sand have been found identical with those of sterilized soil. In general, the sand cultures have shown results equal to and usually surpassing those of the best soil treatments, and much superior to those of untreated soil or treated seed.

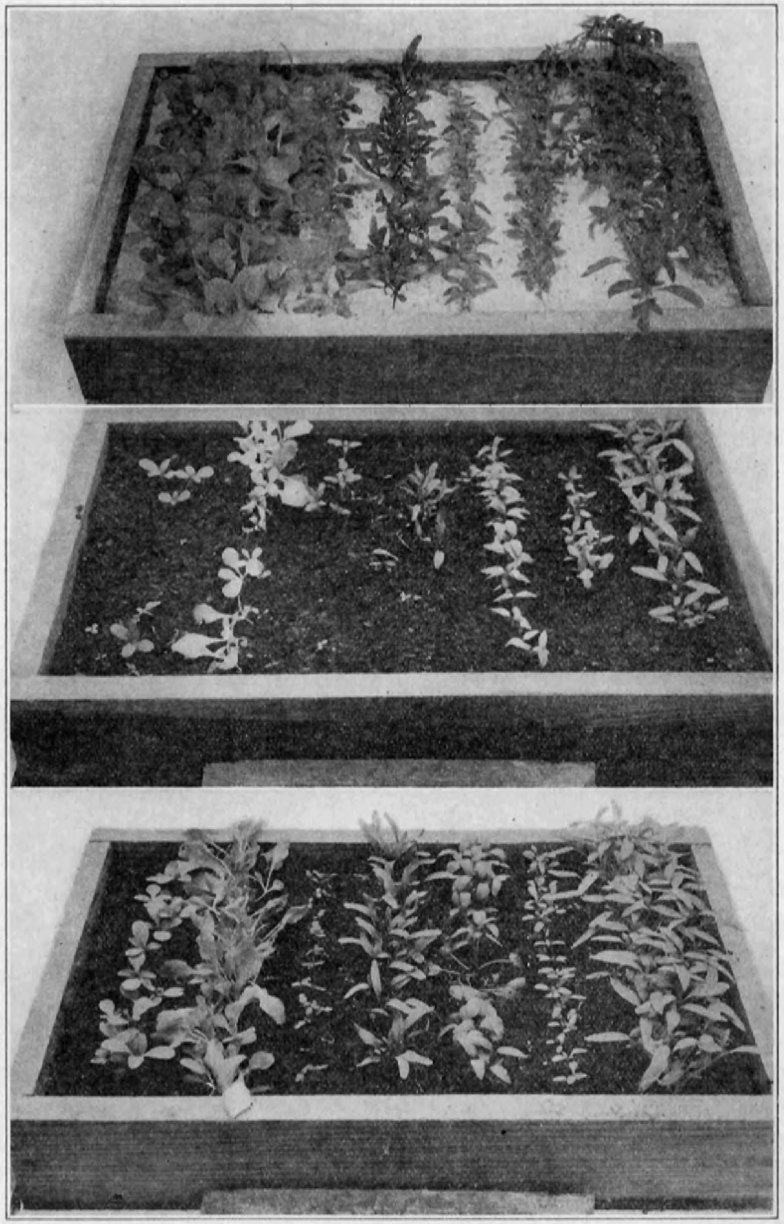


Figure 68

On these facing pages are pictured the results of seedling culture in sand and in soil. Each of the flats contained the same number of seeds of the following species: Zinnia, lettuce, clarkia, beet, eggplant, gypsophila and tomato.

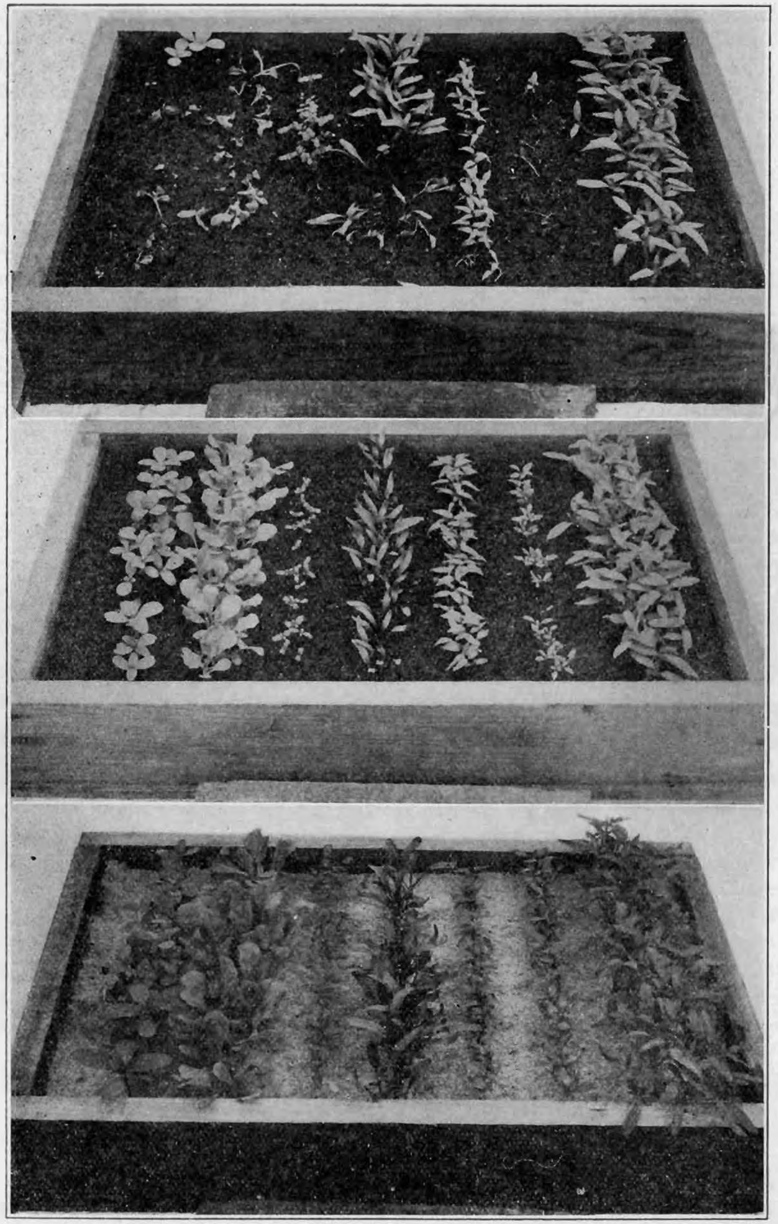


Figure 69

At the top of the left hand page, seedlings are shown growing in gray sand; the center flat contains untreated soil, and below is the formaldehyde-treated soil. On this page are shown from top to bottom: results when seed was treated with red copper oxide and planted in untreated soil; autoclaved soil, and brown sand.

Under certain conditions, a large amount of failure in seedling production is due to other causes than the visible loss of seedlings after they have emerged (post-emergence damping-off). As Horsfall (11) has pointed out, many seedlings are attacked by fungi before they show above the soil or even before the seed sprouts (pre-emergence damping-off). Formaldehyde, if used in amounts exceeding the tolerance of the seed, will cause poor germination or stunting of the young seedlings. Also, reduced germination and much slower growth often occur in soil which has been heated.

In order to show the relative amounts of post-emergence damping-off among the soil cultures and in the sand, the numbers of emerged seedlings that were destroyed are listed in Table 2, for eight representative species. This table shows the relatively large number of seedlings that were damped-off after emergence in the plain soil and seed-treatment cultures, and the comparatively few so destroyed in the treated soils and sand. Here, again, the sand culture shows the least post-emergence damping-off.

TABLE 2. NUMBER OF SEEDLINGS DAMPED-OFF AFTER EMERGENCE. PERCENTAGE OF SEEDS PLANTED

SPECIES	SOIL				SAND
	Untreated	Cuprous Oxide on Seed	Formaldehyde Treated	Autoclaved	
Beet	52	70	14	7	3
Clarkia	10	12	5	0	0
Cucumber	19	15	1	4	0
Eggplant	14	52	7	1	0
Gypsophila	11	18	6	5	1
Lettuce	24	20	0	2	0
Spinach	18	31	23	2	1
Tomato	8	2	0	0	0

By combining the data in Table 2 with the corresponding figures for the same species in Table 1, an approximation may be obtained of the total number of seedlings which emerged from the soil and sand in each case. It will be noted that when seed was treated with red copper oxide and planted in soil naturally infected with *Rhizoctonia*, a large number of seedlings came up, although later serious losses occurred through damping-off. These results are less satisfactory than those of Horsfall (11) and Horsfall, Newhall and Guterman (12), who used cuprous oxide on seeds in soil infected with *Pythium*. Alexander, Young and Kiger (1), however, have expressed doubt as to the real effectiveness of any form of seed treatment. The fungicide on the seed probably is effective only in a very limited area near the seed itself. Once the seedling grows beyond this disinfected zone, infection may take place.

The results given in Tables 1 and 2 show that formaldehyde may convert the soil into a satisfactory medium for growing seedlings. An average high production of healthy plants and usually a low incidence of disease may be obtained by this method. However, care must be taken to add enough formaldehyde to control the damping-off organisms without injuring the seedlings. This adjustment has been found difficult when seedlings are sensitive to formaldehyde. In the two tables, the results of formaldehyde treatment have been taken only from those experiments in which the best damping-off control was obtained together with minimum seedling injury, either with treatment in the form of formaldehyde dust or with the liquid. On many occasions in the course of this work, damping-off has occurred in the same cultures in which the seedlings showed injury from the formaldehyde treatment of the soil.

Throughout this investigation, the best damping-off control in the naturally infected soil has probably been obtained by means of autoclaving. At times, many consecutive cultures have been grown by this method with only the occasional loss of a few seedlings. Unfortunately, the proper sterilization of the soil, such as has been the aim here, is an exacting procedure and requires considerable time, labor and equipment. Meanwhile reduced germination and poor seedling growth have been encountered too frequently in the autoclaved soil. Finally, recontamination or incomplete sterilization have at times resulted in the loss of certain seedling cultures even with this method. See Figure 67 (2).

It has been noted in Table 2 that small percentages of certain seedlings have been damped-off in the sand cultures. These losses were of individual seedlings and the spread of the fungus to neighboring plants took place slowly, if at all. No epidemic of damping-off has been found in this work in any of the young cultures, when the sand was thoroughly washed before the seeds were planted. Large seeds, such as beans or cucumber, and seeds with heavy coats, such as beets or spinach, seem to show this solitary type of damping-off in a sterile medium more frequently. Undoubtedly certain seeds harbor various fungi either externally or internally which, as pointed out by Chen (6), may become parasitic under conditions favorable for the fungus.

Occasionally, among the older cultures of certain seedlings such as tobacco or gypsophila, where a large number of small seedlings are usually grown massed together for a long period of time, an epidemic type of damping-off may occur. In such cases *Pythium* has often been found to be the predominating fungus and the disease apparently spreads by contact of the above-ground parts of the infected and healthy seedlings. Losses of this sort have been common in formaldehyde-treated soil cultures, probably after the sterilizing effects of the chemical had diffused away; and also in cultures of autoclaved soil. In sand cultures this type of damping-off has appeared in a few cases, but always a number of days after the same disease had appeared in treated soil under the same conditions. It is possible that infection of this kind may come from some external source, such as water. In this connection it is interesting to note that Böning (4) found it necessary to supplement chemical soil treatments with later applications of some fungicidal spray to the seedlings in order best to control damping-off in tobacco seedbeds.

Summing up the results in terms of damping-off control, the data are much in favor of the sand culture method. Not only is it the most easily carried out but it shows the most consistent and complete control of seedling diseases.

It is suggested for the present that soil treatments in use may be more valuable in the preparation of soil into which the seedlings are to be transplanted. It seems from these experiments that washed sand is the best medium for starting the plants from seeds.

Comparative Growth of Seedlings in Sand and Soil

After reading reports of certain experiments with sand culture, one would seem justified in expecting to raise in sand healthy seedlings similar in general respects to those grown in soil. Spencer and Shive (19) have found that seedlings of *Rhododendron ponticum* transplanted at the age of five months from quartz sand that had been watered twice daily with a nutrient solution, were larger and more vigorous than others which were transplanted from a leaf-mold-soil-sand mixture at the age of nine months. Working with more mature carnation plants, on a commercial basis in the greenhouse, Biekart and Connors (3) obtained flowers from sand-grown plants which equalled in both quantity and quality those from plants grown in soil.

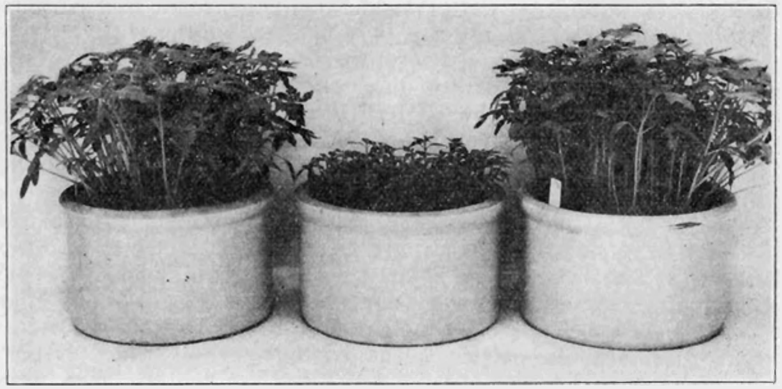
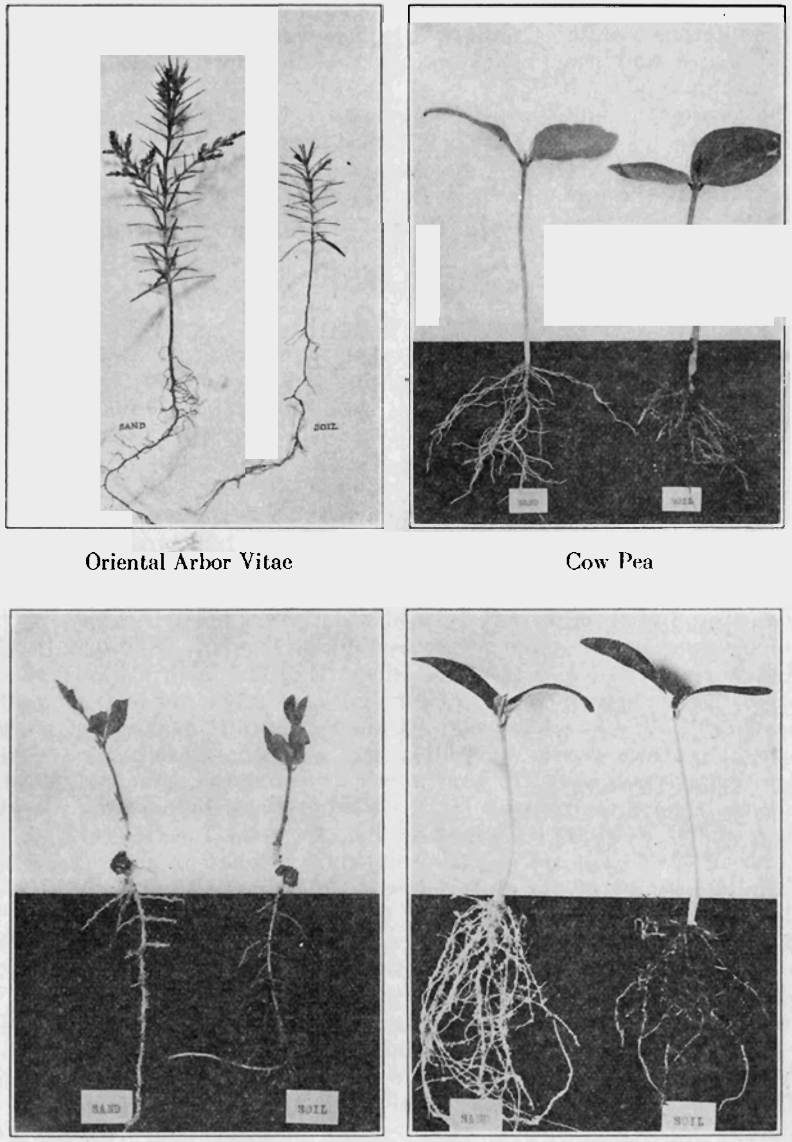


FIGURE 70. Cultures showing the relative sizes of tomato seedlings (left to right) soil, unfertilized sand, sand which received the regular amount of potassium nitrate at time of planting.

In the present studies, it has been noted that the rapidity of germination, emergence, growth, size and vigor of seedlings grown in sand with complete nutrient solutions have compared most favorably with seedlings produced in the best soil cultures. Percentage of germination (estimated by the total number of emerged seedlings) has been found practically the same (spinach possibly excepted) in the sand as in the most productive soil cultures. The relative sizes of five species of soil and sand-grown seedlings are shown in Table 3. In this case the average fresh weight of 100 seedlings taken from cultures having abundant moisture was used to indicate the size.

TABLE 3. SIZE OF SEEDLINGS IN SOIL AND SAND.

SPECIES	AGE	Fresh Weight of 100 Seedlings in Grams				
		SOIL				SAND
	Days after Planting	Untreated	Cuprous Oxide on Seed	Formaldehyde Treated	Autoclaved	
Beet	22	18.3	14.8	24.5	12.1	28.7
Gypsophila	22	5.2	6.4	6.1	4.9	8.5
Lettuce	18	9.9	15.2	15.2	8.0	19.4
Spruce	50	1.7	1.6	1.7	1.6	2.2
Tomato	18	22.2	24.3	30.5	20.6	32.3



Oriental Arbor Vitae — Cow Pea

Sweet Pea — Cucumber

FIGURE 71. Root development of seedlings in sand and in soil.

Most seedlings have the advantage of forming an excellent root system when grown in sand. The roots are strong enough to allow the plant to be forcibly pulled up without too serious damage to the system. Seedlings removed from soil in a similar manner are likely to be seriously lacking in roots, even though the soil is loose. Spencer and Shive (19) noticed this excellent root development on rhododendron seedlings in sand. In this connection, Anderson and Cheyney (2) found that certain coniferous seedlings showed varying root development in different types of soil and they believed that the mechanical resistance of the soil was an important factor.

The possession of large, strong roots by sand-grown seedlings is an important factor in the transplanting process. Less care is necessary in removing the seedlings from sand and consequently less time is required. Also, these plants are more likely to survive. Figure 71 shows the relative root developments of seedlings from sand and from soil.

Other Advantages of the Sand-culture Method

The growth of weeds among seedlings in soil sometimes becomes a difficult problem, even if the soil has received certain treatments. Slow growing seedlings may be overshadowed by vigorous weeds that are present in the soil. In washed sand the only foreign plants in the culture are those introduced as impurities with the seed.

Watering of the sand cultures is a much less exacting process than in the case of soil. Biekart and Connors (3) state that sand requires no more water than soil for growing carnations in the greenhouse. They also observe that sand absorbs the water evenly, whereas with soil, if the bed is not level, there is a tendency for it to accumulate in local areas which might cause branch rot or stem rot to develop. Our experiments demonstrated that sand may be watered thoroughly without danger of inducing damping-off among the seedlings. On the other hand, Alexander, Young and Kiger (1) have shown that soil with a high moisture content has lower percentages of seedling emergence and higher seedling losses from both *Rhizoctonia* and *Pythium*. Since it is possible to water the sand cultures more thoroughly, less frequent watering is required.

Another advantage of the sand method is that the same sand may be used year after year, by washing it with hot water before each planting. It is usually necessary to renew soil at frequent intervals. Also, the fertility of the soil is never definitely known, whereas clean sand with a definite amount of the nutrient salts added, produces seedlings of a uniform size having similar rates of growth each year.

It is also possible, as is shown later, to regulate the growth of seedlings in sand to a certain degree so that they will not produce stems that are too long for transplanting and will not grow into "stemy" plants. As far as has been learned, no such control of growth has ever been advocated for soil culture. In sand culture again, the ultimate size of the seedlings may also be determined and regulated by the amount of fertilizer supplied, while in soil, growth continues indefinitely until many of the plants are too large for transplanting. Sand-grown seedlings have always been uniform in size at all stages of development. At times, they have been kept in sand for several weeks before transplanting without any loss in numbers and with no detriment to later growth. With a little experience in fertilizing the sand, the seedlings may be brought up to a desired size and maintained approximately at that size for extended periods until they are needed. The above practices are only possible with an infertile medium.

After the seedlings were transplanted and established in the soil no consistent differences were noticed in regard to growth and yields of the plants. It was noted, however, that a larger percentage survived the

transplanting process from sand than from soil. This difference was most marked where plants were taken from the untreated soil and was undoubtedly due to the incipient fungous infection being carried to the new soil on many of the seedlings.

The shade of green of young plants, although usually the same in sand as in soil, has not been considered an indicator of health, since Deuber (8) has found that stunted soy bean seedlings grown in distilled water are of a darker green color and even contain more chlorophyll than healthy seedlings grown with a complete nutrient solution.

MATERIALS AND METHOD FOR SEEDLING CULTURE IN SAND

Simplicity of preparation, the small amount of necessary attention to details, and the low cost are desirable features of the sand culture method. All of the needed materials are near at hand and may be secured readily. Of much importance also is the fact that the method allows wide variations from the specified procedure, and even admits of large errors in manipulation without seriously affecting results.

The Sand

Source: It has been determined that the source, color, and fineness of the various sands that were used in this work are relatively unimportant so long as the sand is thoroughly washed in hot water before using. Certain seedlings appeared to grow better in some sands than in others, but no consistent differences have been observed. Pure quartz sand may be used but this requires a more complete nutrient solution for satisfactory results. The experiments also showed that colored sand, such as one would obtain from the seashore, river bar, or inland sand pit, contains mineral impurities that benefit the growth of seedlings. The following table (4) gives the source and certain physical characteristics of the seven different sands most frequently used in these experiments. Three of these (Nos. 2, 3, and 5) were obtained from dealers in builders' supplies.

The seashore and inland-pit sands had a neutral or slightly alkaline reaction (6.9–7.5pH) when washed. They also reduced the acidity of certain nutrient solutions. If washed with hydrochloric acid, however, this alkaline tendency was largely lost. After the seedlings grew and the cultures received considerable watering, the reaction of the sand solution was between 6.8 and 7.4pH in most cases.

Table 4. Physical Characteristics of Sand Used

No.	Color	Source	Size of Particle—by sieve % AIR-DRY. Passing 40-mesh	Between 20- and 40- mesh	Retained by 20- mesh	Water Holding Capacity % by wt.
1	White	Manufactured from quartz	12	86	2	32
2	Gray	So. Shore of Long Island, N.Y.	86	14	0	24
3	Brown	No. Shore of Long Island, N.Y.	27	41	32	20
4	"	Seashore, Ocean Park, Me.	29	66	15	22
5	"	Inland pit, North Haven, Ct.	40	46	14	25
6	Red-Brown	Inland pit, Hamden, Ct.	61	27	12	23
7	"	L. I. Sound, E. Haven, Ct.	45	47	8	24

It has been found possible to grow one crop of seedlings free from damping-off in seashore sand without washing. The small amount of salt included did not severely affect growth. Unwashed sand from inland sources, however, with its larger content of soil-forming materials, sometimes has been found to contain damping-off fungi.

WASHING OF THE SAND: To insure the most satisfactory results, all sand should be washed in hot water before the seeds are planted. This is especially important when the sand has been used for a crop previously, in order to remove the organic material formed by decaying seeds, roots, algae, and bacteria. The best damping-off control and the most rapid seedling growth are secured when the sand has been thoroughly washed several times in hot water (70° C or higher). The procedure here was to place a flat of sand in a water-tight container, cover with hot water to a depth of from two to four inches, and after thoroughly stirring the sand for about a minute to pour the water off. This was repeated until the water appeared practically clear after stirring. In the case of new seashore sand, from three to five changes of water are probably sufficient. With inland sand more washing is sometimes necessary. The whole process requires only a few minutes and for large quantities of sand, an even more rapid method could undoubtedly be invented.

Containers

After washing, the sand may be placed at once in clean containers. These should be deep enough to hold two inches or more of sand and should allow for slight, but not rapid drainage. Seedlings have been grown, however, in less than one inch of sand, and others in water-tight containers. Ordinary wooden flats, with or without drainage holes in the bottom, have been used frequently in this work. Flats with wire-screen bottoms produced slightly smaller seedlings because part of the nutrient salts leached from the sand. Crocks — either glazed or unglazed and with a drainage hole in the bottom—may be used for small amounts of seed. It is believed that satisfactory containers which conform with the above principles, could be used successfully out of doors or in a cold frame. In fact certain trial flats placed in cold frames at the Station gave results similar to those obtained in the greenhouse.

Enough sand was used to make a depth of about two and one-half inches in the flats, while in the crocks and greenhouse bench it was used up to a depth of six to eight inches with excellent results.

Fertilizers

After the surface of the moist sand had been leveled off in the containers, it was sprinkled with a nutrient solution before the seeds were planted. This solution contained small amounts of commercial fertilizers designed to supply the food required by growing seedlings.

It is well known that green plants need several chemical elements for growth. In this work it was found that nitrogen and potassium had to be supplied. The addition of phosphorus to the colored-sand cultures increased the size of the seedlings considerably, although fair-sized, healthy seedlings developed without this treatment. A sufficient quantity of certain elements, such as sulphur, iron, magnesium, and calcium, were apparently present either in the natural sands, as impurities in the fertilizer salts, or within the seed.

For practical purposes, therefore, it was not found necessary to add to the sand all of the elements commonly required for growth. Complete nutrient solutions have usually given larger and also "softer" seedlings, but these are not always more desirable. Smaller seedlings, of a convenient size for handling, with good roots and firm stems, frequently withstand the shock of being transplanted better than those which are larger and more succulent.

FIGURE 72. Lettuce seedlings showing effects of various fertilizer salts on sand. Left to right in front, plain sand; potassium nitrate. In rear, potassium and calcium nitrates; potassium chloride; potassium nitrate and monobasic calcium phosphate.

The attempt has been made here to make the nutrient solution as simple as possible and still capable of producing firm, healthy, actively-growing seedlings, comparable in size with those grown in soil. For this reason, potassium nitrate (KNO_3, nitrate of potash, saltpeter) was used as a source of both nitrogen and potassium. As pointed out above, these are the essential supplements in this method, and it has been found possible to secure good results with this fertilizer alone, as a one-salt solution. For better seedling growth, monobasic calcium phosphate ($CaH_4(PO_4)_2$, soluble portion of commercial superphosphate of lime may be added, making a two-salt solution.

TABLE 5. EFFECTS OF ADDING MONOBASIC CALCIUM PHOSPHATE AND MAGNESIUM SULPHATE TO SAND, AS SHOWN BY SIZE OF SEEDLINGS

Species	Days after Planting	Fresh weight of 100 seedlings—in grams		
		KNO_3	KNO_3 $CaH_4(PO_4)_2$	KNO_3 $CaH_4(PO_4)_2$ $MgSO_4$
Beet	18	17.5	19.4	19.8
Beet	24	26.2	31.0	29.2
Gypsophila	22	8.3	9.5	9.8
Lettuce	22	13.7	14.2	15.5
Tomato	17	17.9	18.9	21.1
Tomato	23	22.9	52.3	47.5

Typical differences in the size of seedlings, resulting from the addition of extra salts to the potassium nitrate solution, are shown in Table 5. These data demonstrate that monobasic calcium phosphate added to the sand gives somewhat larger seedlings than potassium nitrate alone. The further addition of magnesium sulphate ($MgSO_4$, Epsom salts), however, is seen to provide for seedling growth which is only a little if at all better than that obtained with the two-salt solution. In the cases of beet and tomato, the results are given for two different ages of seedlings. Here the older plants showed greater response to the addition of phosphorus than was apparent when they first became large enough for transplanting. The presence of small amounts of phosphorus, even in the cultures which received only potassium nitrate, or in the seed, probably accounts for the satisfactory growth of the seedlings up to a certain point.

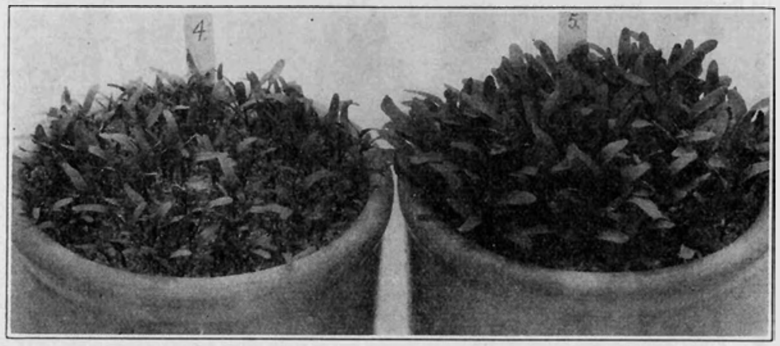


FIGURE 73. Beet seedlings in sand showing the importance of potassium in sand culture. The crock on the left received calcium nitrate; the one on the right received potassium nitrate.

Calcium nitrate (nitrate of lime) and sodium nitrate (nitrate of soda) have been found very satisfactory sources of nitrogen for seedlings in sand culture, provided that potassium is supplied. The use of those materials, therefore, makes the fertilizing process more complicated, since another salt, such as potassium chloride (muriate of potash), or potassium acid phosphate must also be added. However, certain species of seedlings have shown better growth when fertilized with calcium nitrate and potassium acid phosphate (KH_2PO_4) than when saltpeter and monobasic calcium phosphate were used. In keeping with the idea that sodium may partially take the place of potassium in plant food, fair results have been obtained by growing seedlings in sand with sodium nitrate alone. Organic sources of nitrogen have been found unsatisfactory for two reasons: Either the nitrogen may be present in a form not available for quick seedling growth, or the presence of organic substances may encourage the growth of damping-off fungi.

Many investigators have reported that nitrogen in the form of ammonium salts is superior to nitrates for certain species of plants, especially while they are young. However, with the plants used in our work, the best seedling growth was obtained by fertilizing with nitrate salts. Even

the addition of sodium or potassium hydroxide to make the ammonium sulphate solution highly alkaline in reaction (pH 8.0 or above) did not provide for growth in the sand equal to that obtained with carriers of nitrate nitrogen. With these cultures, however, the reaction of the sand solution containing ammonium sulphate became somewhat acid (pH 5.0—5.5) during the growth of the seedlings. This may account for the smaller sizes of the seedlings produced, since Tiedjens and Robbins (20) have shown that tomatoes and soy beans make the most satisfactory growth with ammonium sulphate supplied at a practically constant reaction of around pH 8.0.

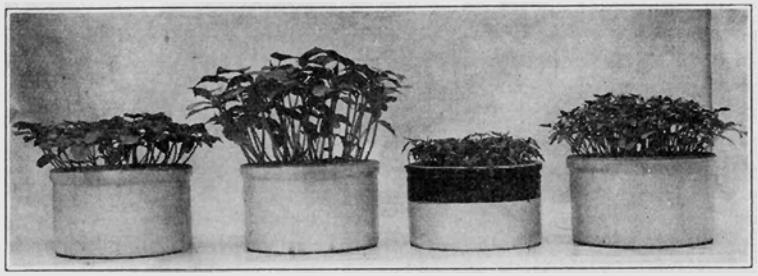


FIGURE 74. Sand cultures showing difference in the length of stems of seedlings fertilized with ammonium sulphate plus potassium chloride as compared with potassium nitrate. Left to right, the first two crocks contain cucumbers, the other two, tomatoes. The sand in one and three received ammonium sulphate and potassium chloride treatment; in two and four, potassium nitrate. Such shortening of the stems is important in the production of certain seedlings that tend to grow too tall.

In connection with the somewhat stunted growth of seedlings nourished with ammonium sulphate, it has also been noted that certain species have shorter stems than those grown with nitrates or in soil. A similar condition has been observed when exceedingly high concentrations of potassium nitrate were used, although the results were less pronounced than in the former case. Because certain rapidly growing seedlings such as cabbage or cucumbers often have elongated stems in the nitrate and soil cultures, it is believed that sand with ammonium sulphate and some potassium carrier may be used to advantage for raising seedlings which are not too "stemy". In every other respect except length of stem (and slightly smaller size) those grown with ammonium sulphate or nitrate are equally desirable for transplanting. Table 6 compares the average sizes of young cucumber seedlings grown in sand with ammonium sulphate, in sand with potassium nitrate, and in soil.

TABLE 6. LENGTH OF STEM AND WEIGHT OF CUCUMBER SEEDLINGS IN SAND AND SOIL CULTURE, 14 DAYS AFTER PLANTING.

Substrata	Nutrient	Average Length of Stem, cm.	Fresh Weight of 100 Seedlings, grams
Sand	Ammonium sulphate and Potassium chloride	4.3	710
Sand	Potassium nitrate	7.9	815
Soil		7.6	785

Although many other sources of phosphorus are available, monobasic calcium phosphate was generally used in this work because it comprises most of the water-soluble portion of the commercial superphosphate, commonly used as an agricultural fertilizer. Potassium acid phosphate, usually obtainable only as a purified chemical, is especially desirable for use with calcium or sodium nitrates, since the necessary potassium is thereby provided. Both of these phosphate carriers give an acid reaction in solution which may be beneficial, since Tiejens and Robbins (20) have shown that nitrate nitrogen is most readily assimilated from solutions, by certain vegetable plants, at a reaction of around pH4 or 5. Also Salter and McIlvaine (14) have given evidence that some seeds germinate better in an acid than in an alkaline medium. The insoluble tribasic calcium phosphate $Ca_3(PO_4)_2$ has been found beneficial as a source of phosphorus for seedlings. Even though this material does not go into solution, Duggar (9) has shown for corn and wheat, that plants may obtain some of the essential elements from relatively insoluble compounds. For some reason, however, bone meal (high in insoluble phosphorus) gave poor results in a few sand culture trials here.

Some plants growing in fairly pure silica sand may show iron chlorosis if this element is not supplied. Snapdragon seedlings, growing in the gray sand listed in Table 4, displayed a lack of green color in the leaves,

FIGURE 75. Culture on left received potassium nitrate and superphosphate. Culture on right received magnesium and iron in addition to these. The species are tomatoes and beets growing in sand.

which was corrected by the addition of traces of some soluble iron salt. With the red-brown and brown sands, however, this chlorosis was not observed. Biekart and Connors (3) found that carnations grown to maturity in sand with a nutrient solution lacking iron did not show iron-starvation, while roses needed extra iron to prevent chlorosis. Duggar (9) reported favorable growth in water cultures with soluble ferric phosphate and this source of iron has been used with success in our investigation. It is believed that much better development has been obtained in many cases by adding a trace of this salt to the one-salt potassium nitrate solution. Undoubtedly the small amount of phosphorus also added, together with the iron, is beneficial.

The addition of calcium to the colored sands was not found necessary for seedling growth, although this element is considered one of the most important in plant nutrition. Certain cultures fertilized with potassium nitrate produced seedlings as large as those from comparable cultures in which part of the potassium salt was replaced by calcium nitrate. In any event, if phosphorus is added as a salt of calcium, a sufficient quantity of this element is provided. (See Figure 72).

If a complete nutrient solution is desired, the type described by Shive (15) or that of Livingston and Tottingham (13) have given some of the best growth obtained with seedlings in sand culture. There is considerable variation, however, among different species of seedlings as to the type of nutrient solution in which the best growth is made. It should also be carefully noted that although the composition of the nutrient solutions used in this work was similar to or identical with that of solutions used by other investigators, the initial concentrations were many times greater in this method of sand culture.

"Complete" fertilization of the sand for seedlings has been satisfactorily obtained by adding a solution of commercial Nitrophoska, or a water extract of a complete fertilizer with some such formula as the common 4-8-7. In the latter case, the danger of introducing soluble organic substances into the clean sand still exists. Cultures of seedlings fertilized with fertilizer-extracts have shown a rather high percentage of damping-off for the sand method.

Amount of Fertilizer

In previous investigations involving the artificial culture of plants either in water or in sand, it has usually been the practice to supply small amounts of nutrient salts at frequent intervals and in relatively dilute solutions. This has been done either by changing regularly the solution in which the plants are growing, or by some system providing a constant flow of the nutrient solution through the culture. Increased growth and continued vigor of the plant apparently justified these steps.

However, it has been found that a sufficient amount of nutrient, added to the sand before the seeds are planted, provides proper nourishment throughout the seedling stage. In the course of this relatively brief period, the physical and chemical conditions of the sand seem to remain entirely favorable for healthy growth and normal root development.

When seeds were planted in the washed sand with no fertilization, the seedlings emerged in fair numbers, but their growth was very limited and they were generally too small for use. (See Figure 70.) If any one of the essential elements was added alone, a variable and slight amount of increase was noted over the unfertilized cultures. With the addition of nitrogen and potassium to the same culture (with or without other essential elements), the seedlings made a definite advance in size and were large enough for transplanting. The amount of growth was found to be proportional, within certain extreme limits, to the amount of nutritive salts added. It may be seen, therefore, that the size of seedlings may be regulated in the feeding process.

Under ordinary greenhouse conditions, with sand three inches deep in flats, it has been found that potassium nitrate, used at the rate of two grams per square foot of sand surface (about three grams to each flat) provides for satisfactory growth of the majority of the seedlings.

Possibly this amount may be increased to advantage if the sand is deeper, or if excessive drainage can take place. Seedlings of practically equal size and vigor have been grown in comparable flats at the same times as the above, with only one gram, of the saltpeter added to each square foot of sand. In some cases this amount has been increased as much as 10 or more times without any important benefit or injury to the seedlings. Other carriers of nitrogen have been used in practically the same amounts as potassium nitrate, since the difference in nitrogen content is revealed only in the ultimate size of the seedlings. The more nitrogen that is supplied, the larger the seedlings will grow, provided other conditions remain the same.

FIGURE 76. Seedlings of the slow-growing gray birch, two months after planting in sand which received no fertilizer after the seeds were planted.

As to the addition of monobasic calcium phosphate, it has been found that an amount approximately 25 per cent by weight of the inorganic nitrogen carrier is sufficient to produce the maximum additional increases in seedling size that may be secured by the use of this material. Since commercial superphosphate contains around 20 or 25 per cent soluble calcium phosphate, the water extract of an amount of superphosphate equal to that of the nitrogen carrier used, would supply enough phosphorus. When nitrogen carriers other than saltpeter have been used, about one-half gram of a potassium salt (usually potassium biphosphate) has been added with each gram of the nitrogen carrier. The ratio of magnesium sulphate to the nitrogen carrier used necessary to produce the maximum increase in growth over that obtained with the nitrate alone, does not exceed 2:10 by weight.

It should be noted that no carefully controlled experiments have been carried out to determine the exact limits to which the concentration of the salts used may be increased without becoming seriously toxic to the various seedlings. Neither have any attempts been made to determine, for the different species and various sands, the exact salts or the proper proportion of these salts that give the optimum seedling growth in sand culture.

* It requires approximately 28 grams to equal one ounce.

By this method, ordinarily it is not necessary to apply extra fertilizer after the seedlings have emerged from the sand. If, however, further growth than that provided by the initial fertilization is desired, a small amount of nutrient solution may be added afterwards. This should contain phosphorus in addition to nitrogen and potassium. As to concentration, a 1 per cent solution (containing 1 part of the dry salts to 99 parts of water) may be safely used in the post-emergence fertilization of most seedlings. The occasional "burning" of some varieties with tender foliage, such as lettuce, makes this practice undesirable. Moreover, it is not necessary to continue supplying nutrients to seedlings in sand after they have ceased to grow in order to keep them for extended periods. Certain cultures of celery seedlings in four inches of sand in crocks have been kept for more than three months without loss or objectionable overgrowth, and without extra fertilization. The desire for large seedlings is the chief reason for applying nutrients after the plants have emerged. With experience, the final size of the seedlings may be regulated by the amount of nitrogen carrier added to the sand before planting.

It is interesting to note that the concentration of the nutrient solution added to the sand is much stronger than that which gives optimum growth of plants in water culture. Of interest also is the fact that the addition of even a dilute nutrient solution to the soil before planting the seeds has often resulted in injury to the young seedlings. On the other hand, frequently solutions with concentrations greater than 10 per cent have been added to sand just before planting without seedling injury. The amount of water in which the fertilizer is dissolved need be only enough to secure even distribution of the nutrients over the surface of the sand. Of course, this solution must become very much diluted by diffusion through the moist sand and by the addition of water before and after the seeds begin to sprout. Furthermore, Breazeale (5) has stated that even the optimum concentration for wheat in sand cultures is around eight times that for water culture. It would seem that the tolerance of seedlings in sand to relatively high salt concentrations is probably in some way due to the presence of the solid sand particles. Incidentally, Shive (16) has presented evidence that particles of washed sand do not adsorb the nutrient salts.

Seeding and Watering

When the sand has been fertilized, the seeds may be planted at once by sowing in drills or broadcasting. Many seedlings seem to develop better when they are grown in fairly dense masses instead of being spaced farther apart. In covering the seed, either moist or dry sand that has received the same washing treatment as the rest may be used, the depth depending for the most part upon the size of the seed. Small seeds germinate well when they are barely covered, while larger ones require enough sand to hold the seedling firmly in place during emergence. Too deep planting, such as placing more than one-half inch of sand over lettuce, reduces the germination.

Watering is the only attention which sand cultures require from the time the seeds are planted until the seedlings are transplanted. The surface should probably be kept continuously moist for best results. Ordinarily, watering once or twice a day, depending upon the sunshine and the amount of evaporation in the greenhouse, is the usual procedure which has been followed in this work. It has been observed that seedlings recover quickly from wilting when the sand becomes too dry. However, Shive (17) found that with one type of sand certain plants grew best when the moisture content of the sand was maintained at slightly more than one-half its total water-holding capacity. By maintaining cultures of seedlings with varying amounts of water in the sand, it has been observed that good seedling growth may be obtained even near the saturation point on the one hand, or near the wilting point on the other. Therefore it seems likely that watering the sand thoroughly at times and allowing it to lose a large portion of its water through evaporation and slight drainage before watering again is a safe method to follow. Such a procedure is the most simple. Probably the most important precaution to be taken is to avoid adding large excesses of water which would drain through the sand and wash out appreciable quantities of the nutrients. As far as is known, the light, temperature, and humidity conditions usually provided for soil culture are also equally favorable for sand culture.

Since the tap water used contains small amounts of nutrient substances that are known to vary in different places, results in growth may differ slightly according to the locality. Likewise, sand from other regions may influence the outcome of this method somewhat. For example, Skeen (18) has shown that "greensands" and "marls", found from New Jersey southward to Georgia, contain sufficient available potassium to support plant growth.

Transplanting of Seedlings

The transplanting process is very easy when the seedlings have been grown in sand. For most rapid work the contents of a flat may be placed in a vessel of water and the plants picked out individually. The water washes the sand away leaving the entire root system clean and moist. Flooding of the culture with water and slightly loosening the sand around the seedlings will accomplish the same results. The young plants may also be removed directly from the sand to soil without the washing process.

Continued Use of the Sand

Sand which has been used for seedling production need not be discarded but should be kept, preferably in a dry condition, for future use. The washing need not be done until it is needed for the next planting. In these experiments, certain sand has been used for more than 12 cultures with equally good results at last as at first. In the raising of carnations, Biekart and Connors (3) used the same natural sand for six years with comparable results each season. Even if damping-off has occurred in the sand, thorough washing in hot water has been found to insure complete freedom from seedling loss.

The growth of green algae on the surface of the sand cultures has been common. However, no injury to the seedlings has been noticed at any time, on account of this contamination. If the plants are vigorous, the shade produced usually prevents a great deal of algal growth.

DIRECTIONS FOR PRACTICAL USE OF THE METHOD

1. Secure the desired amount of sand (as free from silt and loam as possible) from a sand pit, lake, river, seashore, or dealer in masons' supplies.

2. Wash the sand in several changes of hot water (160° F or above) until the water remains practically clean after stirring.

3. Place the sand in *clean* wooden boxes or flats, or any sort of a container that will allow a little drainage. Level off the surface to about 2 inches or more in depth.

4. For each square foot of sand surface, dissolve about one-half teaspoonful of saltpeter (potassium nitrate) in about one-quarter pint of water and sprinkle over the sand. For a flat of ordinary size, this amounts to about 1 teaspoonful of saltpeter dissolved in a cup of water. For larger surfaces add 1 ounce of saltpeter in 3 pints of water for each 10 square feet.

5. Drill or sow seeds and cover with the same washed sand.

6. Keep surface of sand moist by occasional watering until the seedlings are grown.

7. Avoid contamination of the sand by using clean water in watering. Do not add soil to the culture under any conditions. If seeds need more covering after they have sprouted, use only clean, washed sand for this purpose.

SUMMARY

1. Sand culture of seedlings has been found an efficient method of preventing damping-off.

2. An equal number of seeds produced a larger number of seedlings by this method than by culture in plain soil.

3. The sand culture has given results equal to or better than those obtained with the most satisfactory soil treatments. Consistently there has been less damping-off of the seedlings by the sand method than by any of the soil methods used.

4. Germination, emergence, growth, and vigor were equal for seedlings grown in sand and in soil.

5. Sand-grown seedlings were found to have a more favorable size and root development for transplanting and frequently to withstand transplanting better than those grown in soil.

6. It has been found that sand from a variety of sources may be used for the growing of seedlings. Colored sand proved more satisfactory than pure quartz sand.

7. Small amounts of various elements are present in sand. Therefore it was necessary to add only potassium nitrate for satisfactory seedling production of the species included.

8. The addition of phosphorus to the sand has been found to be beneficial and to provide for better seedling growth.

9. Other types of nutrient solutions have been used successfully.

10. The concentration of the fertilizer salts has been found relatively unimportant within certain wide limits.

11. The use of ammonium salts as sources of nitrogen has been found to prevent certain seedlings from developing stems that are too long for transplanting.

12. It has been found possible to add sufficient nutrient to the sand at the time of planting to provide for growth of the plants throughout the seedling stage.

13. Size and duration of growth of the seedlings have been found to depend upon the amount of nutrient added to the sand.

14. Certain seedlings have been kept for long periods of time in sand culture without becoming too large for transplanting.

15. The sand may be used many times if it is washed with hot water before each planting.

16. The growing of seedlings in sand is a simple and efficient method that requires the minimum of care and expense.

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