SPECIAL ARTICLES

A COMPARISON OF WATER CULTURE AND SOIL AS MEDIA FOR CROP PRODUCTION

IN recent years, great interest has been aroused in the possibilities of using a water-culture medium, as an alternative to soil, for purposes of crop production. The idea of making commercial use of the water-culture method, heretofore employed for over three quarters of a century solely for scientific studies, was conceived some time ago by W. F. Gericke, who devised a special technique for growing plants in large tanks filled with nutrient solution.[1,2]

This development was soon given great publicity in the popular press and stimulated wide discussion of the possible social and economic implications of certain proposals for dispensing with the soil as a medium for growing many crops. Such discussion has frequently been based on the following claims: (1) The inherent productive capacity of a given surface of nutrient solution far surpasses that of an equivalent surface of even very fertile soil; either because individual plant yields are higher or because plants can be grown more closely spaced in nutrient solutions than in soil; (2) heating the nutrient solution results in large increases in yields of crops; (3) plants can be grown in nutrient solutions with greater water economy than in soil; (4) food produced by the water-culture method has a higher dietetic value (minerals and vitamins) than that produced in soil; (5) plants grown in nutrient solutions are, in contrast with those grown in soil, free from attack of insects and diseases.

At the suggestion of the director of the California Agricultural Experiment Station, we have undertaken to gain information which would bear directly on the claims listed above, by comparing, under controlled greenhouse conditions, a fertile soil with a favorable nutrient solution, as media for crop production. A full discussion of the results will be published elsewhere, but it is desired to present at this time some of the results and conclusions which may be of general interest.

Since much of the current discussion of the water-culture method is based on work with the tomato, it was adopted as a test plant for this investigation. Tomato plants were grown in a Berkeley greenhouse, in soil and nutrient solution, side by side, with the same spacing and cultural treatment for plants grown in the two media. This arrangement was considered essential to any attempt to compare yields attainable by the two methods. In most popular discussions of the subject, yields of fruit harvested on a small unit of surface, from tomato plants grown in the protection of a greenhouse, for a twelve-months period, have been compared with average field yields under all types of soil and climatic conditions, computed on the basis of large acreages. Such comparisons may be very misleading.

The soil beds occupied the same surface as the tanks of nutrient solution (25 square feet) and consisted of an open-bottom box filled with soil to the depth of two feet. The soil, secured from a commercial greenhouse, had been used successfully in the production of tomatoes. It was autoclaved for 6 to 7 hours prior to use and fertilized with manure, potassium and phosphorus, with the addition of gypsum, in a manner corresponding to the usual fertilization treatment given to that soil under commercial conditions. The nutrient solution, including microelements (solutions A4 and B7), used in the water-culture tanks, has been previously described.[3]

The spacing of plants, the porous bed used in all water-culture tanks, and the heating arrangement used in some soil and water cultures were similar to those described by Gericke and Tavernetti.[2]

Two crops were grown in the course of one calendar year: A fall-winter crop from August to January and a spring-summer crop fom February to August. In the latter period, an aerated unheated nutrient solution and a heated bed of pure sand, 2 feet deep, irrigated daily with nutrient solution, were included in the experiment. The temperature in the heated cultures was maintained around 70° F. in the fall-winter period, and around 75° F. in the spring-summer period. The temperature in the unheated soil and solution varied from 57° to 68° F., depending on the air temperatures.

All plants were staked and trained to single stems, and were allowed to extend to the full height of the greenhouse. Records of individual plant yields were kept only during the spring-summer period (Table II). Since fruit was borne over the entire length of vines, the highest yields were obtained from the tallest

TABLE I

YIELD OF TOMATO* PLANTS GROWN FOR A SIX MONTHS' PERIOD FROM AUGUST TO JANUARY IN SOIL AND NUTRIENT SOLUTION

(20 plants to 25 square feet of surface)

Treatment	Average yield per plant in pounds
Soil heated	6.0
Solution heated	5.7
Soil unheated	6.7
Solution unheated	5.5

* Variety Crackerjack (Earliana).

[1] W. F. Gericke, *Am. Jour. Bot.*, 16: 862, 1929.

[2] W. F. Gericke and J. R. Tavernetti, *Agr. Engineering*, 17: 141–143, 1936.

[3] D. I. Arnon, *Am. Jour. Bot.*, 25: 322–325, 1938.

plants and lower yields from those which could extend only to the lower portion of the sloping greenhouse roof. The highest yields of individual plants from soil and water-culture are given in Table II to indicate the potentialities for fruit production of both media, with relatively unrestricted vertical extension of vines.

TABLE II

YIELD OF TOMATO PLANTS* GROWN FOR A SIX MONTHS' PERIOD FROM FEBRUARY TO AUGUST IN SOIL, SAND AND NUTRIENT SOLUTION

(20 plants to 25 square feet of surface)

Treatment	Average yield per plant in pounds	Highest yield of individual plant in pounds
Soil heated	14.2	28.1
Solution heated	17.0	24.1
Soil unheated	13.9	24.1
Solution unheated	15.7	20.2
Solution unheated, aerated	21.1	28.0
Sand heated	21.6	32.4

* Variety Lloyd Forcing. We are indebted to Dr. W. A. Huelsen, of the Illinois Agricultural Experiment Station, for furnishing the seed.

The yields, on the basis of comparable season and time period, obtained in our experiments with the water-culture method previously described[2,4] were higher than any heretofore reported,[2,4] but considering the variability of cultures, these yields can not be regarded as markedly different from those obtained in soil.[5] The average yields, as well as the highest yields of individual plants, from soil and water cultures do not justify a conclusion that the potential crop yield is higher in a favorable nutrient solution than in a fertile soil. Nor was any evidence found in support of the contention that higher yields per unit of surface can be expected from the water-culture technique as a result of closer spacing of plants than is possible in soil. As already pointed out, the same dense spacing was maintained in the soil beds and in the water-culture tanks and yet no difficulty was experienced in either medium in supplying enough water and nutrients to the plants. The indications were that even under the favorable light conditions prevalent at Berkeley, California, the light factor would determine the most profitable spacing of plants in either soil or nutrient solution, assuming a favorable root environment in both.

Heating the nutrient solution produced no great effect at the two periods of the year on the yield of fruit (Tables I and II). The greenhouse was not heated except on a few occasions to prevent temperatures from falling below 50–55° F. The average Berkeley greenhouse air temperatures during most of the year were sufficiently high to maintain in the unheated cultures a nutrient solution temperature around 65° F., which was adequate for growth. It appears, therefore, that if air temperatures are favorable, the solution temperature will take care of itself.

A marked increase of yield of fruit from unheated nutrient solution resulted from continuous forced aeration. The beneficial effect of improved aeration was also reflected in the growth and yield of plants in sand culture (Table II). There is no reason to believe, however, that comparable yields could not be produced in a soil, which would combine the conditions of optimum aeration, associated with light texture (lighter than that of the soil used in this investigation), with a fully adequate supplying power for nutrients and water. These results suggest, incidentally, that under many climatic conditions aeration of solutions may hold greater promise of increasing yields in commercial water-culture practice than heating the solution.

In the spring-summer experiment records were kept of the amounts of water supplied to the soil and solution cultures. The level of nutrient solution in the tanks was maintained within several inches from the top of the tank, while the usual commercial practice was followed in watering the soil. The experimental data (Table III) indicate that more water was required to produce a unit weight of fruit under water-culture conditions than under soil conditions, although the significance of the difference in water consumption can not be evaluated on the basis of evidence now available.

TABLE III

UTILIZATION OF WATER IN THE PRODUCTION OF TOMATO FRUIT IN SOIL AND NUTRIENT SOLUTIONS

Treatment	Gallons of water used to produce 100 pounds of fruit
Soil heated	214
Solution heated	276
Soil unheated	222
Solution unheated	257

As a part of this investigation, studies of chemical composition and general quality have been made on tomatoes of several varieties grown in the greenhouse in fertile soil, sand and water culture media under the same climatic conditions. No significant difference has been found in the calcium, phosphorus, magnesium, potassium, nitrogen and sulfur content of fruit developed on plants grown in the several media. Neither could any significant difference be found in content of carotene (provitamin A), and vitamin C. Tomatoes harvested from the soil and water-culture could not be consistently distinguished in a test of flavor and general quality.[6]

[4] W. F. Gericke, *Nature*, 141: 536–540, 1938.

[5] Recently data have also become available on yield of potatoes grown in a bed of peat soil in Berkeley. This yield was as large as any heretofore reported as obtained by the water-culture method.

[6] The quality tests were conducted by Dr. Margaret Lee Maxwell, of the Division of Home Economics, and the carotene determinations were made by Dr. Gordon Mackinney, of the Division of Fruit Products, College of Agriculture.

Contrary to some statements, plants grown by the water culture method are not protected against diseases or insects attacking the aerial parts of plants. While the risk of strictly soil-borne disease can be ruled out, recent observations suggest that diseases peculiar to water culture may sometimes attack plants grown in nutrient solutions.

The results of our experiments confirm earlier views that the possibility exists of producing crops on a large scale by the water-culture method. The fact that yields and general quality of plant products are at least equal to those produced under extremely favorable soil conditions (admittedly not generally found) is considered of great interest, but no support was found for the assumption that the potentialities for crop production of a favorable nutrient solution medium far exceed those of a very fertile soil.

A sober appraisal of the commercial possibilities of the water-culture method should be based not on the expectation of fabulous yields, far in excess of any obtainable in soil, or unusual dietary qualities of plant products, but rather on the knowledge that under competent supervision very good crops could be produced in localities favored in climate and water supply, but where good soil is not available or when it is found too expensive to maintain highly favorable soil conditions. Also a water-culture medium when expertly supervised should be subject to more exact control than a soil medium. Other investigators have developed large-scale techniques for growing crops in inert solid media, such as sand and gravel.[7,8]

It must be clearly recognized that the application of the water-culture method for crop production will be limited primarily by economic considerations. What crops could be grown profitably by this method would depend on the value of the crop in the market served in relation to cost of production, which would include a large outlay for tanks and other equipment and materials, as well as special costs of supervision and operation. An important distinction must be made between field and greenhouse operations. It seems highly improbable, in view of the present cost of a commercial water-culture installation and its operation, that crops grown by this method could compete with cheap field-grown crops.[9] In greenhouses specializing in high-priced, out-of-season crops the method appears to have commercial possibilities. The expense of growing greenhouse crops in soil, including cost of equipment for sterilizing soils, may frequently stand comparison with the cost of growing crops by the water-culture method.

However, before any one undertakes to grow plants by the water-culture method, even in greenhouses, he should give the most careful consideration to the economic factors involved and to the need for expert guidance, in the absence of which commercial success is unlikely. The practical experience which many growers have acquired in growing plants in soil may prove of little avail in solving some unfamiliar problems of water-culture technique. It is suggested that those who contemplate installation of the water-culture method for commercial purposes make a preliminary test with a few tanks, to learn some of the requirements of the process.

The suggestion that important amounts of food could be produced economically in small-scale installations for home use has no sound basis, because of high costs of the installations and technical requirements for the successful use of the method.

The continued importance of the use of water-culture technique, as one important method of scientific experimentation in investigations of problems of plant nutrition, needs to be stressed. The development of large-scale water-culture techniques enhances the usefulness of the water-culture method as an experimental tool, by widening its scope of application to problems which involve growing plants to maturity on a large scale and under controlled conditions of nutrition.

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[7] H. M. Biekart and C. H. Connors, *New Jersey Agr. Exp. Sta. Bul.* 588, 1935.

[8] R. B. Withrow and J. P. Biebel, *Purdue Agr. Exp. Sta. Cir.* 232, 1937.

[9] Recently, popular journals have discussed a project for growing vegetables in tanks of nutrient solution, on Wake Island, in Mid-Pacific, to supply fresh vegetables (which constitute only a small proportion of the total food requirements) for the inhabitants of the island and for passengers of the Clipper airships. This, however, is a special case, and there is no reason to assume that it has any general agricultural significance.

THE CHORIO-ALLANTOIC MEMBRANE OF THE DEVELOPING CHICK AS A MEDIUM FOR THE CULTIVATION AND HISTO-PATHOLOGIC STUDY OF PATHO-GENIC FUNGI

ALTHOUGH the chorio-allantoic membrane of the developing chick has been used by numerous investigators as a medium for the cultivation and study of many bacteria, viruses, Rickettsiae and recently of a spirochete,[1] it has not been used extensively (as far as could be determined) for the study of fungi. Goodpasture[2] mentioned these micro-organisms in his Leo Loeb Lecture at the Washington University School of Medicine, on March 24, 1938, and in personal correspondence stated, "we have never made any consistent investigation of fungus infection in this host" (embryo chick). The purpose of this paper is to report briefly

[1] G. Morrow, J. T. Syverton, W. W. Stiles and G. P. Berry, SCIENCE, 88: 384, 1938.

[2] E. W. Goodpasture, *Am. Jour. Hyg.*, 28: 111, 1938.