

A COMPARATIVE STUDY OF SALT REQUIREMENTS FOR YOUNG AND FOR MATURE BUCKWHEAT PLANTS IN SAND CULTURES

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In a recent paper (9) presenting the results of a comparative study of salt requirements for buckwheat plants grown in solution cultures during two different periods of their development, it was announced that similar experiments were carried out with these plants in sand cultures corresponding to the solution cultures. The results of this experimental work with buckwheat in sand cultures furnishes the subject matter of the present paper, which also compares these results with those obtained from the corresponding solution cultures of the earlier work.¹

As previously stated, the object of these investigations was to determine the salt requirements demanded for approximately optimum growth of buckwheat plants during the early stages of their development while the vegetative processes are extremely active, and to compare these with the relative salt proportions best adapted to the development of these plants during the reproductive stages and during the period of seed formation. The entire active life period of the plants was thus divided into two partial periods extending over nearly equal intervals of time, these partial periods representing distinct physiological phases of development. The first of these covered the period between the germination of the seeds and the beginning of the flowering stage, while the second extended from the close of the first period to the maturity of the seeds.

EXPERIMENTAL PROCEDURE AND METHODS

1. *The culture solutions*

Throughout these tests an optimal series of 3-salt solutions (7) was employed in sand cultures. This series was composed of 36 different solutions including all the possible proportions of the three salts, mono-potassium phosphate, calcium nitrate, and magnesium sulfate, when the partial concentrations of each of the components were made to vary by equal increments of one-tenth

¹ A preliminary report giving some of the principal results of these studies has already appeared: Shive, J. W., and Martin, W. M., Ref. No. 8.

of the total osmotic concentration. Each solution had an initial total concentration value of approximately 1.75 atmospheres. Previous experiments have shown that this concentration is well within the range required for optimum growth of buckwheat. The partial osmotic concentration values, as well as the volume-molecular partial concentrations of each salt in these solutions, have been calculated according to the method employed by Tottingham (10, p. 177-182 and 192). A table giving the formulas of the solutions of this series has already appeared in several publications (5, 7) and need not be repeated here. The methods used in preparing the stock solutions, and the necessary manipulations with reference to the making up of the nutrient solutions were practically the same as were those previously described (7).

2. *The sand cultures with renewal of solutions*

The substratum employed with the cultures of these tests consisted of white quartz sand which had previously been thoroughly washed with tap water followed with distilled water. For the first washing the sand was placed in a granite-ware tub and a stream of water from a hose was then directed into the sand, allowing the water to overflow the sides of the tub while the sand was constantly being agitated. This process was continued until the water overflowing the tub was clear of all sediment. The surplus tap water was then decanted, after which the sand was washed twice with distilled water by pouring the water on the sand in the tub and stirring the sand in this water. After the final washing with distilled water the sand was spread on large sheets of paper until air-dry. This sand had a water-holding capacity of 24.9 per cent (average of six determinations) on the dry-weight basis, determined according to the method of Hilgard (2), which employs sheet metal pans with lateral walls 1 cm. high, the bottoms being perforated. The percentages of different-sized particles of sand, obtained by a mechanical separation, are given in table 1.

TABLE 1

Mechanical analysis of sand giving the percentages of the different-sized particles

	<i>per cent</i>
Gravel (more than 2.0 mm.).....	0.58
Fine gravel (2.0 mm. to 1.0 mm.).....	5.67
Coarse sand (1.0 mm. to 0.5 mm.).....	30.83
Medium sand (0.5 mm. to 0.317 mm.).....	53.89
Fine sand (0.317 mm. to 0.254 mm.).....	7.36
Very fine sand (less than 0.254 mm.).....	1.67

The culture vessels consisted of glazed earthenware pots, each with a capacity of about 2 liters; 2.5 kgm. of sand were used for each culture. To provide for the removal of the solutions from the sand cultures, a method similar to that devised by McCall (4) was here adopted. A glass tube with an inside diameter of 4 mm. was placed vertically against the wall of the pot, extending through the sand to the bottom of the pot. The tube was screened at its

lower end by means of a plug of glass wool which prevented the escape of any grains of sand when suction was applied to the top of the tube. To prevent the plug from being drawn through the tube when suction was applied for the removal of the solution, a tuft of the glass wool attached to the plug was allowed to extend 1.5 cm. to 2.0 cm. beyond the end of the glass tube. The sand resting upon this tuft held the plug firmly in place. After the sand (2500 gm.) had been weighed into the pot, a paraffined paper funnel was placed in the inverted position at the center of the sand surface. The lower end of the funnel was buried in the sand to the depth of about 1 cm. These funnels, which were about 6 cm. in length with a diameter of 2 cm. at one end and about 4 cm. at the other, were made of heavy paper and were then thoroughly impregnated with melted paraffine to render them impervious to moisture. To prepare the dry sand in each pot for the planting of the seedlings, the nutrient solution was poured into the sand through the funnel until the sand was nearly saturated. The sand culture was then ready to receive the seedlings.

The "Japanese" variety of buckwheat was employed. The seed used was from the same lot as was used in the earlier work with solution cultures corresponding to the sand cultures of the present study. The seeds were germinated and the seedlings grown on a germinating net in the manner described in a previous publication (7). When the seedlings were about 5 cm. tall, those selected for uniformity were carefully transferred to the pots of sand which had previously been prepared in such a way as to provide for the renewal of the solutions in the sand at regular intervals during the growth period. Five seedlings were transplanted to each pot, after which a sufficient amount of the solution was added through the funnel to flood the culture until the free solution stood above the sand to the depth of 1 cm. or more. This served to fix the roots of the seedlings in place and to smooth the surface of the sand. With this initial application, 750 cc. of solution were added to the sand of each culture. Suction was then applied to the top of the glass tube (provided for the removal of the solution) by means of an aspirating pump and the withdrawal of the solution was continued until the sand was reduced to the desired moisture content, which throughout these tests was maintained at approximately 15 per cent of the dry weight of the sand, or 60 per cent of its water-holding capacity. Two more portions of the solution (250 cc. to each portion) were then passed through the sand, the moisture content being reduced each time to the desired 60 per cent of its moisture-holding capacity. The culture was then sealed. This was done by pouring over the surface of the sand a thin layer of melted Briggs and Shantz (1) wax, thus completely covering the sand between the walls of the pot and the funnel. The sealing of the cultures was rendered necessary in order to prevent evaporation and the consequent disturbing factor of salt precipitation at the surface of the sand, and in order also to control the concentration of the nutrient solution and to make possible the measurement of water loss by transpiration.

At the end of each three or four day period, each pot was weighed and a sufficient amount of distilled water was added through the funnel to restore the entire system to its original weight, after which a fresh nutrient solution was added (250 cc. to each culture) while at the same time an equal quantity was withdrawn through the glass tube provided for the purpose.

The transpirational water loss from the plants, during a given interval of time, is supplied, of course, through the absorption by the roots of an approximately equal quantity from the solution in the medium in which the plants are rooted. This process results in a gradual increase in the concentration of the solution. In order to prevent any excessive variations in the concentration of the nutrient solutions, due to the absorption by the roots, the cultures were weighed at 2-day intervals during the early growth stages and daily during the later stages of growth. At each weighing a sufficient quantity of distilled water was added to each culture to restore that which had been absorbed by the roots during the interval in question. The amount of water added to each culture at any weighing was approximately equal, of course, to the amount lost by transpiration during the interval directly preceding the weighing. A record was kept of the amounts of water added from time to time. The total amount of water lost during the entire growth period was obtained by summing the losses for the partial periods between each two successive weighings.

3. Early period of development

In order to determine the best proportions of the three salts KH_2PO_4 , $\text{Ca}(\text{NO}_3)_2$, and MgSO_4 , for the growth of buckwheat tops and of roots in sand cultures during the early developmental period, between the germination of the seed and the flowering stage, 36 sand cultures were prepared, as above described, with the 36 different solutions of the 3-salt series employed in these tests. All the seedlings used were selected for uniformity of size and vigor. These were carefully removed from the germination net, one at a time, when about 4 cm. tall, and were transplanted to the sand cultures previously prepared, 5 seedlings to each culture. One culture was prepared also with Knop's solution and another with Tottingham's best solution for wheat tops, each with a total osmotic concentration value (1.75 atmospheres) equal to that of the solutions of the 3-salt series. These cultures were added to the series for comparison.

This series of sand cultures was now continued with renewal of solutions every three or four days, until the plants began to bloom. This required a time period of 25 days after the seedlings had been transferred to the sand cultures. The series was then repeated.

At the end of the growth period the wax seal was removed from the cultures and the tops of the plants were severed from the roots just at the surface of the sand. The tops were then dried to constant weight at a temperature of

about 103°C. and the dry weights obtained. The method employed in harvesting the roots was essentially the same as that adopted by McCall (5). In order to wash the roots as free from sand as possible, the contents of each culture pot, after the tops of the plants had been removed, were transferred to a sieve with meshes sufficiently large to allow all the sand grains to pass through. The sand was then washed through the sieve by means of a gentle stream of water, leaving the roots on the sieve. The roots, together with some adhering sand grains, were dried to constant weight in the same manner as were the tops. The dried roots with the adhering sand were then weighed, after which the roots were ignited in crucibles of fused silica until all the organic matter had been destroyed. The loss in weight due to the ignition process was taken to represent the approximate dry weight of the roots, assuming, of course, that the adhering sand suffered no loss in weight in the ignition process. The small amount of ash resulting from the ignition of the roots was considered negligible, since, as McCall pointed out, the relative weights would be affected only by the differences between the weights of ash from the various individual cultures.

Throughout these experiments daily records were kept of the temperature and moisture conditions in the greenhouse where the cultures were conducted. Maximum and minimum temperature readings were obtained from thermometers protected from direct sunlight, and the evaporating power of the air was measured by means of the daily rates of water loss from standardized, spherical, porous-cup atmometers. The readings obtained from these instruments were corrected to the Livingston (3) standard spherical cup by multiplying the actual readings by the coefficient of correction of the cups used.

The first of the two series conducted during the early developmental period extended from April 12 to May 7, 1917. During the period of this series the highest temperature recorded was 33°C. (on April 23), and the lowest was 7°C. (on April 18). The water loss from the porous cup atmometer gave a daily mean of 9.8 cc., a maximum daily rate of 20.9 cc. (on April 18), a minimum daily rate of 2.9 cc. (on April 27), and a total loss from the instrument of 244.6 cc. for the entire period. The second series, which was just like the first, was carried out between May 24 and June 18, 1917. During this time the maximum temperature reached was 35°C. (on June 11), and the minimum was 9°C. (on May 26). The evaporation rate from the atmometer gave a daily mean of 12.6 cc., a maximum daily rate of 21.6 cc. (on June 4), a minimum daily rate of 2.0 cc. (on May 29), and a total loss of 313.6 cc. for the entire period. For the sake of convenience in presenting the data, this double series will be designated series A throughout.

4. Late period of development

The tests dealing with the questions of salt requirements for the buckwheat during the later growth period were begun with plants which had reached the stage of development attained by those harvested at the end of the early

period of growth, when the plants had just reached the flowering stage. In order to obtain a sufficient number of plants at this stage of development, which were all nearly alike in size and vigor, the following procedure was adopted:

A larger number of sand cultures than that required for the series was prepared. Carefully selected seedlings were transplanted to these cultures, five seedlings to each culture, in the manner above described. Each of these sand cultures was provided with the solution² of the optimal 3-salt series producing the highest yield of buckwheat tops and roots during the first four weeks after germination. These cultures were continued to the flowering stage, with renewal of solutions every third or fourth day, covering an early growth period of 25 days after the seedlings had been transferred to the sand cultures. During this time all the plants were grown in the same nutritive medium and under approximately similar conditions of temperature, light, and moisture. This procedure gave very uniform plants.

At the end of the early 25-day growth period, 36 cultures were selected from the larger number at hand. The solutions in these and cultures were now replaced by the 36 different solutions of the optimal 3-salt series. This was accomplished by passing through the sand of each culture (after first adding sufficient distilled water to bring the entire system back to its original weight) a triple portion (750 cc.) of the new solution, thus flushing out the old solution and replacing it with the new. One culture with Knop's solution and one with Tottingham's best solution for wheat tops were also included in the series for comparison. These were treated in the same manner as were the other cultures of the series. The series was now continued with renewal of solutions every third or fourth day as before, until practically all the seeds were ripe. This second, or late, developmental period extended over a time interval of 30 days. The entire active growth period of the plants, after the seedlings had been transferred to the sand cultures, extended over an interval of 55 days.

At the end of the active growth period the plants were harvested and the dry weight yields obtained in the same manner as were those of series A, representing the early developmental period. The yields of tops, roots and seeds were obtained separately.

During the active growth period, extending from April 25 to June 19, the maximum temperature experienced by the cultures was 35°C. (on June 11), and the minimum was 9°C. (on May 26). The water loss from the atmometer, indicating the evaporating power of the air, gave a daily mean of 12.4 cc., a maximum and a minimum daily rate of 23.2 cc. and 2.0 cc. on June 5 and May 29, respectively, and a total loss from the instrument of 680.2 cc. for the entire time period. The series was repeated between July 2 and August 27. During this time a maximum temperature of 38°C.

² This solution contained the three salts in the following volume-molecular partial concentrations: KH_2PO_4 , 0.144 m.; $\text{Ca}(\text{NO}_3)_2$, 0.0052 m.; and MgSO_4 , 0.0200 m.

was reached on August 1, and a minimum of 14° C. on July 12. The rate of evaporation from the atmometer gave a daily mean of 17.1 cc., a maximum and a minimum daily rate of 35.1 cc. and 3.3 cc. on August 26 and July 12, respectively, and a total loss of 938.9 cc. for the entire time period. This double series will be designated series B, throughout this study.

EXPERIMENTAL RESULTS

As previously stated, a comparative study of the growth of buckwheat plants in water cultures, corresponding to the present study with sand cultures, has already been carried out. The methods of presenting the results obtained with the two double series of cultures here considered will, therefore, follow the same general outline as that employed in the earlier work (9).

The behavior of the *young* buckwheat plants (series A, early developmental period) in the different sand cultures provided with the solutions of the optimal 3-salt series, will be compared with the behavior of the *older* plants (series B, late period of development) grown in sand cultures provided with solutions of the same series. The comparison will be made by means of three kinds of direct quantitative measurements: (1) dry weights of tops, (2) dry weights of roots, and (3) total transpirational water loss from the plants during the entire growth periods. Further comparisons will be made of two other quantitative criteria derived from the transpiration values considered in connection with the dry weights of tops and of roots. These are (1) water requirements of tops and (2) water requirements of roots. These values represent the transpirational water loss for each single gram of dry plant substance produced. The dry weights of seeds will also be considered in connection with the data of series B.

I. Dry-weight yields

A. Presentation of data

Since the tops and roots of series A, and the tops, roots, and seeds of series B were weighed separately, two sets of dry-weight measurements are available for the former series and three for the latter. The dry-weight values of tops and of roots of series A are presented in table 2, and in a similar manner those of series B are given in table 3. In the first column of each table are given the culture numbers referring to the positions which the cultures occupy on the triangular diagram³ graphically representing the variations in the salt proportions of the culture solutions of the series here employed in sand cultures.

Since, as above stated, each of the two series was repeated, each dry weight datum, as given in the tables, represents the average yield obtained from two corresponding cultures. The tables give the average absolute dry weights, in grams, and also the relative values of these in terms of the corresponding value

³ For the description of this diagram see Shive (7) and McCall (5).

TABLE 2

Average dry weights of tops and roots of buckwheat grown to the flowering stage in sand cultures supplied with three-salt solutions, all having a total osmotic concentration value of 1.75 atmospheres, but differing from each other in the proportions of the constituent salts

CULTURE NUMBER	AVERAGE DRY-WEIGHT YIELDS			
	Tops (5 plants)		Roots (5 plants)	
	Absolute	Relative to R ₁ C ₁ as unity	Absolute	Relative to R ₁ C ₁ as unity
	gm.		gm.	
R ₁ C ₁	1.875	1.00	0.276	1.00
C ₂	2.850	1.52	0.292	1.06
C ₃	2.858	1.52	0.250	0.91
C ₄	3.145	1.68	0.334	1.21
C ₅	3.072	1.64	0.328	1.19
C ₆	3.186	1.70	0.333	1.21
C ₇	3.642	1.94	0.363	1.31
C ₈	2.860	1.52	0.294	1.06
R ₂ C ₁	2.023	1.08	0.224	0.81
C ₂	3.492	1.86	0.382	1.38
C ₃	3.648	1.95	0.376	1.36
C ₄	3.423	1.82	0.316	1.15
C ₅	3.566	1.90	0.384	1.39
C ₆	3.854	2.05	0.409	1.48
C ₇	2.803	1.49	0.318	1.15
R ₃ C ₁	2.560	1.36	0.279	1.01
C ₂	3.825	2.04	0.312	1.13
C ₃	3.542	1.89	0.427	1.55
C ₄	3.456	1.84	0.406	1.47
C ₅	3.508	1.87	0.391	1.42
C ₆	3.164	1.69	0.317	1.15
R ₄ C ₁	2.695	1.44	0.339	1.23
C ₂	4.457	2.38	0.373	1.35
C ₃	4.141	2.20	0.388	1.41
C ₄	3.748	2.00	0.402	1.46
C ₅	3.746	2.00	0.398	1.44
R ₅ C ₁	2.228	1.19	0.235	0.85
C ₂	2.971	1.58	0.287	1.04
C ₃	3.888	2.08	0.319	1.15
C ₄	3.707	1.98	0.456	1.65
R ₆ C ₁	2.382	1.27	0.298	1.08
C ₂	3.397	1.81	0.399	1.44
C ₃	3.472	1.85	0.358	1.30
R ₇ C ₁	2.419	1.29	0.291	1.05
C ₂	2.996	1.60	0.316	1.14
R ₈ C ₁	2.515	1.34	0.200	0.73
K*	3.187	1.70	0.319	1.15
T*	3.577	1.91	0.392	1.42

* In this table and in subsequent tables K and T represent cultures prepared with Knop's solution and with Tottingham's best solution, respectively. The data obtained from these cultures are introduced for comparison.

TABLE 3

Average dry weights of tops, roots, and seeds of buckwheat grown from the flowering stage to maturity in sand cultures supplied with three-salt solutions, all having a total osmotic concentration value of 1.75 atmospheres but differing from each other in the proportions of the constituent salts

CULTURE NUMBER	AVERAGE DRY-WEIGHT YIELDS						RATIO OF TOPS TO SEEDS
	Tops (5 plants)		Roots (5 plants)		Seeds (5 plants)		
	Absolute	Relative to R ₁ C ₁ as unity	Absolute	Relative to R ₁ C ₁ as unity	Absolute	Relative to R ₁ C ₁ as unity	
	gm.		gm.		gm.		
R ₁ C ₁	5.345	1.00	0.690	1.00	2.980	1.00	1.79
C ₂	6.346	1.17	0.783	1.13	3.332	1.12	1.91
C ₃	7.696	1.44	1.003	1.45	4.328	1.45	1.78
C ₄	8.825	1.65	0.905	1.31	4.694	1.57	1.88
C ₅	8.957	1.68	0.935	1.36	4.306	1.45	2.08
C ₆	7.523	1.40	0.723	1.05	3.696	1.24	2.03
C ₇	8.168	1.53	0.828	1.20	2.804	0.94	2.92
C ₈	9.287	1.72	0.812	1.18	2.681	0.90	3.46
R ₂ C ₁	5.599	1.05	0.680	0.99	2.246	0.76	2.49
C ₂	6.678	1.25	0.737	1.07	2.137	0.72	3.12
C ₃	8.863	1.66	0.985	1.43	3.176	1.07	2.78
C ₄	8.889	1.66	1.029	1.49	3.895	1.31	2.28
C ₅	9.364	1.75	1.142	1.65	4.230	1.42	2.21
C ₆	9.599	1.80	1.132	1.64	3.058	1.03	3.14
C ₇	8.135	1.52	0.926	1.34	3.260	1.09	2.51
R ₃ C ₁	7.911	1.48	0.691	1.00	2.120	0.71	3.73
C ₂	8.492	1.59	0.651	0.94	2.647	0.89	3.20
C ₃	8.544	1.60	1.157	1.68	3.174	1.06	2.69
C ₄	10.298	1.93	1.114	1.63	4.249	1.43	2.42
C ₅	12.314	2.30	1.300	1.88	5.001	1.68	2.46
C ₆	9.501	1.78	1.117	1.62	4.304	1.44	2.21
R ₄ C ₁	6.783	1.27	0.768	1.11	2.325	0.78	2.92
C ₂	8.316	1.56	1.063	1.54	3.752	1.26	2.22
C ₃	8.726	1.64	0.886	1.28	4.190	1.41	2.08
C ₄	9.853	1.84	1.215	1.76	3.238	1.09	3.04
C ₅	6.831	1.28	0.805	1.17	3.122	1.05	2.19
R ₅ C ₁	5.528	1.03	0.795	1.15	3.651	1.22	1.51
C ₂	8.772	1.64	1.017	1.47	2.204	0.74	3.98
C ₃	8.943	1.67	1.087	1.58	3.594	1.20	2.49
C ₄	9.160	1.71	0.873	1.27	2.657	0.89	3.44
R ₆ C ₁	6.000	1.12	0.788	1.14	2.754	0.92	2.18
C ₂	8.255	1.55	1.085	1.57	3.761	1.26	2.20
C ₃	7.973	1.49	0.535	0.78	3.257	1.09	2.44
R ₇ C ₁	6.231	1.16	0.802	1.16	3.105	1.04	2.00
C ₂	7.023	1.31	0.682	0.97	3.250	1.09	2.16
R ₈ C ₁	5.897	1.10	0.677	0.98	2.830	0.95	2.08
K	8.708	1.63	1.070	1.55	4.046	1.36	2.15
T	8.737	1.64	0.907	1.31	3.456	1.16	2.53

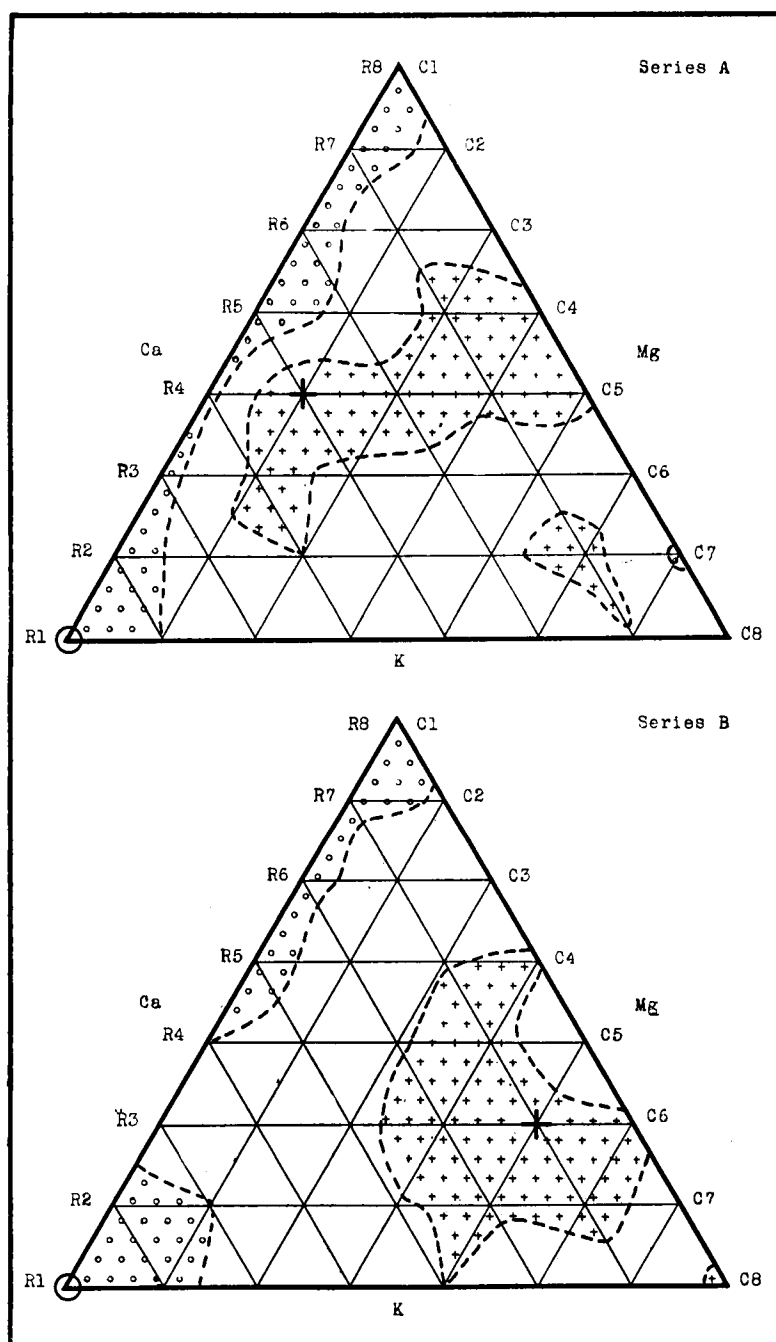


FIG. 1. DIAGRAMS SHOWING RELATIVE YIELDS OF BUCKWHEAT TOPS

Areas of high yields indicated by small crosses, those of low yields by small circles. The culture of each diagram giving the highest yield is marked by a larger cross, that giving the lowest yield by a larger circle.

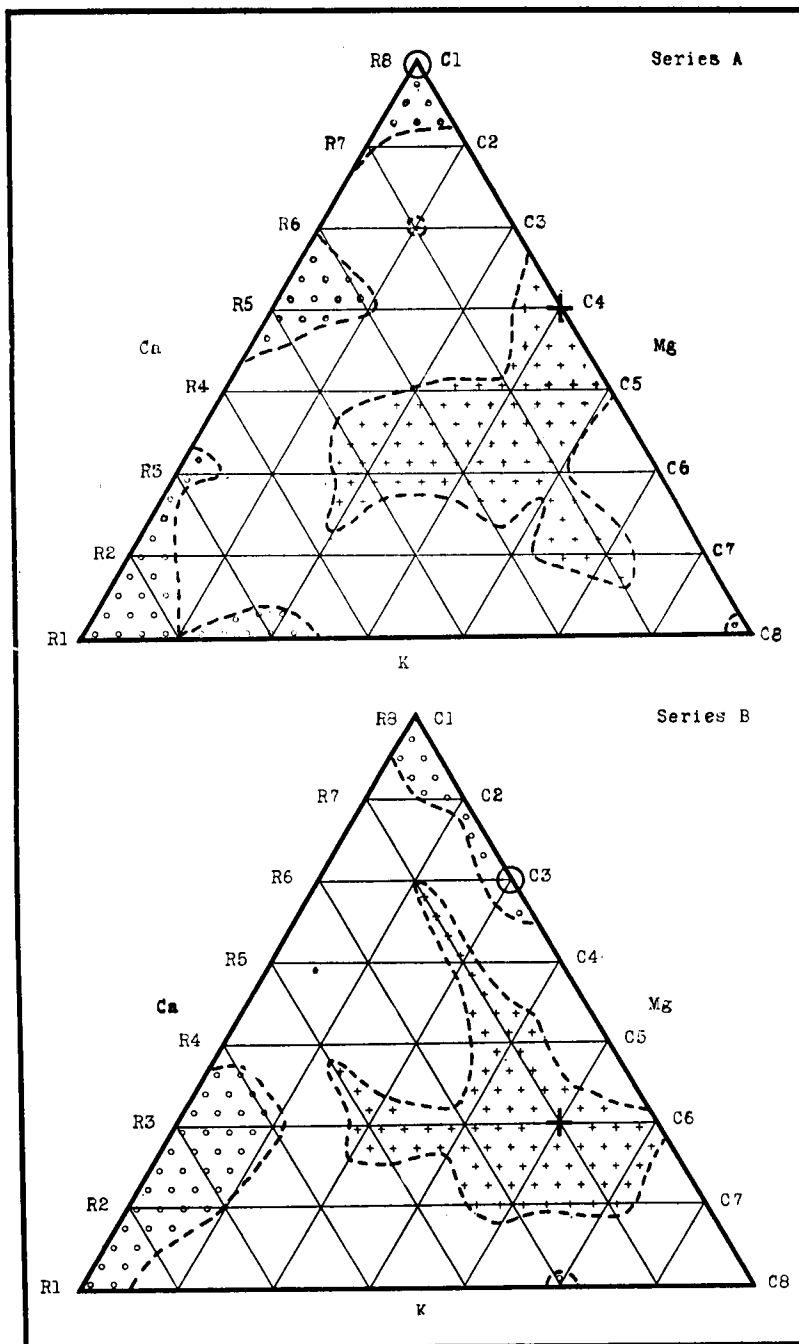


FIG. 2. DIAGRAMS SHOWING RELATIVE YIELDS OF BUCKWHEAT ROOTS

Areas of high yields indicated by small crosses, those of low yields by small circles. The culture of each diagram giving the highest yield is marked by a larger cross, that giving the lowest yield by a larger circle.

for culture R_1C_1 considered as 1.00. The highest relative yields are here indicated in black-face type. In the last column of table 3 are given the ratios of tops to seeds. The last two items in each column refer to the yields obtained from the sand cultures treated with Knop's solution and Tottingham's best solution for wheat, respectively. These were included in each series for comparison.

For facility in making comparisons, the relative yield values of series A and series B were here plotted on the triangular diagrams in the same manner as

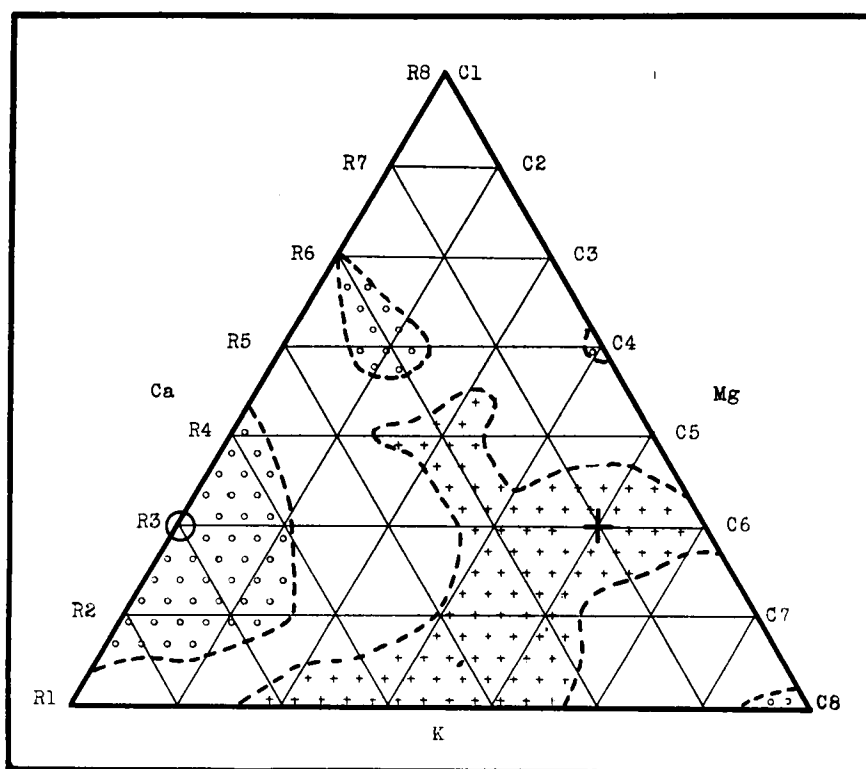


FIG. 3. DIAGRAM SHOWING RELATIVE YIELDS OF BUCKWHEAT SEEDS

Area of high yields indicated by small crosses; areas of low yields indicated by small circles. The culture giving the highest yield is marked by a larger cross, that giving the lowest yield by a larger circle.

were the yield values obtained from buckwheat plants grown in the culture solutions of the earlier work, corresponding to the sand cultures of the present study. At the intersections of the lines showing the culture locations on the diagrams of figures 1 to 3, were placed the numbers representing the average relative dry weights taken directly from the proper columns of tables 2 and 3.

Each diagram thus graphically represents the distribution of the yield values in its respective series. In order better to study the growth rates, each series of 36 cultures was divided into three groups. One group comprises the nine cultures giving the highest yields, another group includes the nine cultures giving the lowest yields, and the remaining eighteen cultures giving medium yields comprise a third group. The positions occupied by these three groups of cultures are outlined on the diagrams of figures 1 to 3, and they correspond to the areas of high, low, and medium yields, but the yield values are omitted from the diagrams to avoid confusion. The position of any culture may readily be located on the diagram by means of its culture number, which always indicates the row and the number of the culture in the row. The rows are numbered consecutively on the left margin of each diagram, from base to apex. The culture positions in each row, represented by the intersections of the lines, are considered as numbered consecutively from left to right, the number of the last culture position in each row being given on the right margin of the diagram. The areas of high yields, corresponding to the range of the yield values for the best nine cultures, are indicated on the diagram by small crosses. The areas of low yields, corresponding to the range of the dry-weight values for the poorest nine cultures, are marked by small circles. The position on the diagram of the culture giving the *highest* yield is marked by a larger cross, and that of the culture giving the *lowest* dry weight value is shown by a larger circle.

B. Dry weights of tops

The relations of the various salt proportions to the growth rates of the buckwheat plants during the two different developmental periods here considered, can best be compared by referring to the triangular diagrams of figure 1. The average relative dry weights of tops, as given in the third column of table 2 (series A), are here graphically represented in the upper diagram, while the lower diagram graphically represents the corresponding data of table 3 (series B). The comparisons will proceed with reference to the ranges of the high and low average dry-weight values of tops, or with respect to the extent of the corresponding areas of high and low yields as outlined on the diagrams. It is to be remembered that the position of any culture or the range of any area on these triangular diagrams, is a graphic representation of the osmotic proportions of the three salts as they occur in the solution of that culture, or of the range of these proportions in the cultures giving high or low dry weights of tops, assuming, of course, that the proportions of the salts are not altered when the solutions are introduced into the sand cultures.

1. *Early period of development (series A, fig. 1).* It will be observed that on the diagram of series A (fig. 1) the main area of low yields, including eight of the nine cultures embraced within the range of low (1.00–1.49) dry weights of tops, extends along the entire left margin of the diagram. Culture R₂C₇ marks the upper limit of the range of low yields. The main area of high

yields (1.95–2.38) occupies a central region on the triangle, extending to the right margin at cultures R_4C_5 and R_5C_4 . This region includes eight of the nine cultures producing high yields of tops. A secondary high area is also indicated about culture R_2C_6 .

The lowest yield of tops in this series occurred with culture R_1C_1 , while the highest is shown for culture R_4C_2 . The yield from this culture is 138 per cent higher than the corresponding yield from culture R_1C_1 . The solution of the sand culture (R_4C_2) producing the highest dry weight of tops is characterized by having four-tenths of its total osmotic concentration due to mono-potassium phosphate, two-tenths due to calcium nitrate, and four-tenths due to magnesium sulfate. The total range of the average relative dry weights of tops for this series extends from 1.00 to 2.38.

2. *Late period of development (series B, fig. 1).* The average dry weights of tops for the series representing the growth period between the flowering stage and maturity, range from 1.00 to 2.30, relative to the average yield from culture R_1C_1 . The diagram representing the average yields of this series shows two areas of low dry weights (1.00–1.27) on the left margin, one extending to the base and the other to the apex of the triangle. The main area of high yields, embracing eight cultures, occupies a region lying principally to the right of the vertical axis of the diagram, extending to the right margin at cultures R_5C_4 and R_3C_6 , and touching the base of the triangle at culture R_1C_5 . A secondary high area occurs also at the extreme lower right.

The lowest yield occurred with culture R_1C_1 . The highest dry weight of tops was produced by culture R_3C_5 . The solution of this culture is characterized by having three-tenths of its total osmotic concentration supplied by mono-potassium phosphate, five-tenths by calcium nitrate, and two-tenths by magnesium sulfate. The yield from this culture was 130 per cent higher than the corresponding yield from culture R_1C_1 .

3. *Comparison of the effects of the various salt proportions upon the growth rates during the two different developmental periods. Consideration of the relative dry weights of tops (fig. 1).* From a comparison of the diagram representing the yields obtained during the early growth period (series A) with that representing the corresponding yields obtained during the late period of development (series B), it is readily apparent that there is a marked similarity between the two diagrams with respect to the positions of the areas of low top yields. Out of a total of nine cultures in each series producing low dry weights of tops, seven are included in the areas of low yields on both diagrams of figure 1. These seven cultures are included in the left marginal row, and all are characterized by low partial osmotic concentrations of calcium nitrate, but they embrace the whole range of partial concentrations of both the other salts. It thus appears that the buckwheat plants, during both the early and late developmental periods of growth, respond in much the same way to the left marginal solutions when these are supplied to the plants in a sand medium. The lowest average dry weight of tops occurred with culture R_1C_1 in both series A and series B.

Turning now to the cultures which produced high yields, it is at once apparent that there is no marked similarity between the two series with respect to the positions and ranges of the areas of high dry weights of tops as outlined on the diagrams representing the two series. Of the nine cultures in each series producing high yields, three cultures only (R_2C_5 , R_4C_4 , and R_5C_4) are included in the areas of high yields on both diagrams. Culture R_4C_2 in series A, and R_3C_5 in series B, each producing the highest yield of tops in its respective series, are shown to occupy positions on opposite sides of the diagrams. The osmotic proportions of the three salts characterizing the former are markedly different from those which characterize the latter. The maximum yield of tops was produced during the early period of development in a sand medium provided with a solution having a higher osmotic proportion of mono-potassium phosphate, a much lower proportion of calcium nitrate, and a much higher one of magnesium sulfate than had the solution in the sand culture which gave the highest yield of tops during the late developmental period (series B). Thus, with respect to the groups of cultures producing high yields of tops, it is at once clear that the response of the plants to the proportions of the three salts in the various solutions supplied to the sand cultures, is markedly different during the two different developmental growth periods represented by series A and series B.

The readiness with which the older plants of series B respond to the variations in the proportions of the salts in the different solutions, is brought out by a comparison of the total ranges of the average relative top yields of the two series. The variations in the average relative yield values for series A extend from 1.00 to 2.38, giving a total range in these values of 1.38 from the lowest to the highest. The corresponding yield values of series B vary from 1.00 to 2.30, showing a total range of 1.30, from the lowest to the highest value. It will thus be observed that the highest yield value for each of the two series is more than double that of the lowest.

It is interesting here to compare the salt proportions producing the highest yields and the lowest yields in the sand cultures of the present study with those giving the best and the poorest yields in the corresponding series of solution cultures previously carried out. A comparison of the best sand culture of the series conducted during the early period of development (series A) with the best solution culture of the corresponding series, brings out the fact that the salt proportions of these two cultures are the same. These are the salt proportions of culture R_4C_2 , the highest yield of tops occurring with this culture in each of the two corresponding series in question. The poorest sand culture and the poorest solution culture in the corresponding series carried out during the early growth period, show a marked difference in the proportions of the three salts. The former has the salt proportions of culture R_1C_1 , while the latter is characterized by those of culture R_1C_4 . A similar comparison of the best and the poorest physiological balance of salt proportions for the growth of buckwheat tops in sand cultures and in solution cultures carried out during

the late period of development (series B) shows that the two series agree in the proportions of the three salts required for the best yields. They agree also in the salt proportions giving the poorest dry weights of tops. In each of these two series the highest yield occurred with the salt proportions of culture R_3C_5 , and the poorest yield with those of culture R_1C_1 . It thus appears that the physiological properties of the nutrient solutions giving the highest yields of buckwheat tops are not greatly disturbed by the introduction of these solutions into the sand cultures, when these properties are judged by their relative effects upon the plants grown in the solutions and in sand cultures provided with the solutions. This is clearly indicated by the perfect agreement between the salt proportions characterizing the cultures giving maximum yields in the corresponding series of sand and solution cultures. Agreements similar to those here pointed out are indicated for other salt proportions characterizing cultures which produced high yields, as well as some which gave low yields, in corresponding series of sand and solution cultures, but these can best be brought out by a comparison of the triangular diagrams representing the series in question.

4. *Comparison of the ion ratio values and the ranges of these for high and for low yields of tops.* The cation ratio values and the ranges of these for the cultures giving the best nine and the poorest nine yields of buckwheat tops for each of the two series here considered, are presented in table 4. The table is divided into two vertical sections. The first column in each section gives the culture numbers and this is followed by three columns giving the ion ratio values and the total ranges of these for the best and the poorest nine cultures of the series indicated at the top. The cultures are arranged in the descending order of the magnitudes of the Mg/Ca ratio. At the bottom of the table are given the maximum and minimum values and the total range of these for the entire series. The ratio values of the culture giving the highest yield in each series are indicated in black-face type, while those of the culture giving the lowest dry weight in each series appear in italics. The cultures included in table 4 are comprised in the areas of high and of low yields outlined on the triangular diagram of figure 1.

From a comparison of the ion ratio values for the group of cultures producing high yields of tops in series A, with those of the corresponding group of series B, as given in table 4, it is at once evident that there is no substantial agreement between the two series with respect to the ranges in the values of any of the three cation ratios, Mg/Ca, Mg/K, and Ca/K. In series A the group of cultures giving high yields is characterized by a relatively narrow range in the magnitudes of each of the three ratios. The ratio ranges of this group of cultures are restricted to the lower one-third of the corresponding total ranges of the entire series. Series B, on the other hand, shows a low range (0.24 to 1.54) in the values of the Mg/Ca ratio, a medium range (0.28 to 5.55) for the ratio Mg/K, and a relatively wide range (0.58 to 5.76) in the values of the ratio Ca/K. During the early period of development, therefore, good growth of

tops was associated with Mg/Ca ratio values between 0.38 and 4.81; with Mg/K ratio values between 0.28 and 3.47; and with values of the Ca/K ratio between 0.36 and 2.16. During the late period of development good growth of tops occurred with ranges in the ratio values as follows: Mg/Ca between 0.24 and 1.54; Mg/K between 0.28 and 5.55; and Ca/K between 0.58 and 5.76.

The highest yielding cultures, R_4C_2 in series A, and R_3C_5 in series B, agree

TABLE 4

Cation ratio values and ranges of these values for cultures producing high and low yields (best nine and poorest nine cultures, respectively) of buckwheat tops during the early and the late developmental periods

	SERIES A (FIRST 4-WEEK GROWTH PERIOD)				SERIES B (SECOND 4-WEEK GROWTH PERIOD)			
	Culture number	Mg/Ca	Mg/K	Ca/K	Culture number	Mg/Ca	Mg/K	Ca/K
High yields.....	R_1C_2	4.81	2.32	0.48	R_1C_5	1.54	5.55	3.60
	R_4C_2	3.85	1.39	0.36	R_3C_4	1.44	1.39	0.96
	R_2C_3	3.21	3.47	1.08	R_2C_5	1.15	2.08	1.80
	R_1C_3	1.92	1.04	0.54	R_4C_4	0.96	0.69	0.72
	R_5C_3	1.28	0.56	0.43	R_3C_5	0.77	0.93	1.20
	R_1C_4	0.96	0.69	0.72	R_2C_6	0.64	1.39	2.16
	R_2C_6	0.64	1.39	2.16	R_5C_4	0.48	0.28	0.58
	R_5C_4	0.48	0.28	0.58	R_3C_6	0.32	0.46	1.44
	R_4C_5	0.38	0.35	0.90	R_1C_6	0.24	1.39	5.76
Range.....		4.43	3.19	1.80		1.30	5.27	5.18
Low yields.....	R_1C_1	15.40	11.10	0.72	R_1C_1	15.40	11.10	0.72
	R_2C_1	13.46	4.86	0.36	R_2C_1	13.46	4.86	0.36
	R_3C_1	11.55	2.78	0.24	R_4C_1	9.61	1.74	0.18
	R_4C_1	9.61	1.74	0.18	R_5C_1	7.70	1.11	0.14
	R_5C_1	7.70	1.11	0.14	R_1C_2	6.74	9.72	1.44
	R_6C_1	5.77	0.69	0.12	R_2C_2	5.77	4.17	0.72
	R_7C_1	3.85	0.40	0.10	R_6C_1	5.77	0.69	0.12
	R_8C_1	1.92	0.18	0.09	R_7C_1	3.85	0.40	0.10
	R_2C_7	0.27	0.69	2.52	R_8C_1	1.92	0.18	0.09
Range.....		15.13	10.92	2.43		13.48	10.92	1.35
Entire series	Maximum	15.40	11.10	5.76				
	Minimum	0.24	0.18	0.09				
	Range....	15.16	10.92	5.67				

in showing relatively low values for all three ratios, although there is considerable difference in the corresponding ratio values of the two cultures. The values of the three ratios Mg/Ca, Mg/K, and Ca/K for the culture giving the highest yield of tops in series A are 3.85, 1.39, and 0.36, respectively, and the corresponding values for the culture producing the highest yield of tops in series B are 0.77, 0.93, and 1.20, respectively.

A similar comparison of the ranges in ratio values for the group of lowest-yielding cultures in series A with those of the corresponding group in series B, brings out the fact that these two groups agree in showing very wide ranges in the values of the two ratios Mg/K and Mg/Ca, and a relatively narrow range in the values of the ratio Ca/K. Each of the two groups embraces the entire range of the values of the Mg/K ratio. Each group also includes the highest value of the Mg/Ca ratio and the lowest value of the ratio Ca/K.

The two series agree in showing the lowest yield for the same culture, R₁C₁. This culture is characterized by the highest value of the ratios Mg/Ca (15.40) and Mg/K (11.10), and by a relatively low value of the ratio Ca/K (0.72).

From a consideration of these data it appears that the relation between the growth rates and the ion ratio values is markedly different for the group of cultures producing high yields during the early developmental periods and the group giving corresponding yields during the late period of development. On the other hand, there is a striking similarity, with respect to this relation, between the group of low-yielding cultures of series A and that of series B.

C. Dry weights of roots.

The average relative dry weights of roots as given in the last column of table 2, for series A, and in the fifth column of table 3 for series B, are represented graphically on the diagrams of figure 2. The upper diagram represents the data of the root yields of the young plants obtained at the flowering stage, while the lower diagram represents the corresponding data of the yields of the older plants, obtained at maturity. These two diagrams, like those of figure 1, representing the average relative yields of tops, will be compared with reference to the ranges of the yield values of the best nine and of the poorest nine cultures, and also with respect to the positions and extent of the corresponding areas of high and low yield values as these are outlined on the diagrams.

1. *Early period of development (series A, fig. 2).* On the diagram of series A (fig. 1), the low yields (0.73–1.06) are represented as occupying three areas bordering on the left margin of the diagram. Cultures R₁C₂ and R₁C₈ each mark the upper limit in the ranges of low-yield values. Both cultures are, therefore, included in the group of cultures giving low yields. The main area of high yields (1.41–1.65), occupies a central region on the diagram, extending to the right margin at cultures R₄C₅ and R₅C₄. This area includes eight of the group of nine cultures producing high yields. A secondary high area is indicated about culture R₆C₂.

The lowest yield of buckwheat roots in this series occurred with culture R₃C₁. The highest yield is shown for culture R₅C₄. The yield from this culture is 65 per cent higher than the corresponding yield from culture R₁C₁. The solution furnished to the sand medium of this culture is characterized by having five-tenths of its total osmotic concentration due to mono-potassium

phosphate, four-tenths due to calcium nitrate, and one-tenth to magnesium sulfate. The total range in the values of the average relative dry weights of roots of this series extends from 0.73 to 1.65.

2. *Late period of development (series B, fig. 2).* The main area of low (0.78–1.07) average yields represented on the diagram of this series occupies a region bordering on the lower left margin and extends to the base of the triangle. Another low area, including three cultures, borders on the upper right margin and extends to the apex of the diagram. A small low area is also indicated about culture R_1C_6 . The high (1.57–1.88) average yields of roots are represented on the diagram by a single area occupying a central region mainly to the right of the vertical axis of the diagram, and extending to the right margin at culture R_3C_6 .

The lowest average yield of roots in this series was produced by culture R_6C_3 . The highest yield occurred with culture R_3C_6 , and was 88 per cent higher than the corresponding yield from culture R_1C_1 . The solution supplied to the sand of the highest-yielding culture derived three-tenths of its total osmotic concentration from mono-potassium phosphate, five-tenths from calcium nitrate, and two-tenths from magnesium sulfate. The total range in the yield values obtained from the cultures of this series extends from 0.78 to 1.88, relative to the yield from culture R_1C_1 .

3. *Comparison of the effects of the various salt proportions upon the growth rates during the two different developmental periods. Consideration of the relative dry weights of roots (fig. 2.)* A comparison of the two diagrams of figure 2, representing the yield data obtained from the young plants at the flowering stage (series A), and the corresponding data obtained from the mature plants (series B), shows the agreements and the disagreements between the two series, with respect to the distribution of the areas of low yields, to be nearly equally divided. The area of low yields at the lower left of the diagram of series A has a somewhat corresponding area on the diagram of series B. The four cultures R_1C_1 , R_2C_1 , R_3C_1 , and R_8C_1 are included in the areas of low yields of roots on both diagrams. With respect to the remaining areas of low yields, the two diagrams show no similarity. The lowest yield of roots in series A occurred with culture R_8C_1 , while series B shows the lowest yield for culture R_6C_3 .

The two diagrams of figure 2 show a certain degree of similarity with respect to the areas representing high average yields of roots. This is indicated by the fact that six of the nine highest-yielding cultures in series A appear also in the area of high root yields on the diagram of series B. The highest yields of roots, however, are shown for different cultures in the two series. The highest yield in series A occurred with culture R_5C_4 . This culture is indicated as producing a low medium yield in series B. The highest yield of roots in series B is shown for culture R_3C_6 . Thus the maximum yield of roots was produced during the early period of development in a sand medium provided with a solution having a higher osmotic proportion of mono-potassium phos-

phate and a lower proportion of both calcium nitrate and magnesium sulfate than had the solution in the sand culture giving the highest yield of roots during the late period of development. While it has been shown that there is a certain degree of similarity between the areas of high yields on the diagrams representing the relative dry weights of roots of series A and of series B, it is evident that there is considerable difference in the manner in which the roots of the two series responded to the variations in the proportions of the three salts. This is clearly indicated by the fact that neither the lowest nor the highest dry weights of roots occurred with corresponding cultures of the two series.

It has already been shown by a comparison of the total ranges of the average relative values of the top yields of the two series, that the older plants of series B responded quite as readily to the variations in the proportions of the salts in the solutions of the different cultures as did the young plants of series A. This is emphasized also by a similar comparison of the total ranges in the values of the relative dry weights of roots of the two series. The variations in the relative yield values of the roots of series A extend from 0.73 to 1.65, showing a total range of 0.92. The corresponding yield values of series B vary from 0.78 to 1.88, giving a total range of 1.10 from the lowest to the highest value. It will thus be observed that the range in the yield values of series B is somewhat higher than that of series A. The highest yield value for each of the two series is more than double that of the lowest, which is true also in the case of top yields.

A comparison of the diagrams of figure 2 with the corresponding ones of figure 1, brings out some interesting correlations between the growth of tops and of roots. Thus, five of the nine cultures giving high yields of tops in series A are included also in the areas of high root yields, and six cultures included in areas of low top yields appear also in the areas of low root yields. In this series, however, the *highest* yield of tops and of roots occurred with different cultures, as did also the *lowest* yield of tops and of roots.

On the diagram representing the relative yields obtained at the end of the late developmental period (series B), the main area of high top yields and that of high root yields are in very good agreement. In this series the highest yield of tops and of roots occurred with the same culture, R_3C_6 . Five cultures giving low top yields also produced low yields of roots. But the lowest dry weights of tops and of roots are shown for different cultures.

4. *Comparison of the ion ratio values and the ranges of these for high and low yields of roots.* Table 5 presents the cation ratio values and the ranges of these values for the cultures giving the best nine and the poorest nine yields of buckwheat roots for each of the two periods of development here considered. This table conforms in every respect to table 4. Inspection of table 5 brings out the fact that the two series agree in showing a relatively low range in the values of each of the three cation ratios for the group of cultures in both series producing high root yields. The ratio ranges for this group of cultures in

both series are restricted to the lower one-third of the corresponding total ranges for the entire series. These ranges lie near, but do not include, the lowest values of the respective ratios occurring in the entire series. From this it appears that good growth of roots during each of the two periods of development was associated with low values of all three cation ratios. It will be observed, however, that there is considerable difference between the range values

TABLE 5

Ion ratio values and ranges of these values for cultures producing high and low yields (best nine and poorest nine cultures, respectively) of buckwheat roots during the early and the late developmental periods

	SERIES A (FIRST 4-WEEK GROWTH PERIOD)				SERIES B (SECOND 4-WEEK GROWTH PERIOD)			
	Culture number	Mg/Ca	Mg/K	Ca/K	Culture number	Mg/Ca	Mg/K	Ca/K
High yields.....	R ₃ C ₃	2.56	1.85	0.72	R ₂ C ₅	1.15	2.08	1.80
	R ₄ C ₃	1.92	1.04	0.54	R ₄ C ₃	2.56	1.85	0.72
	R ₆ C ₂	1.92	0.46	0.24	R ₆ C ₂	1.92	0.46	0.24
	R ₃ C ₄	1.44	1.39	0.96	R ₃ C ₄	1.44	1.39	0.96
	R ₄ C ₄	0.96	0.69	0.72	R ₄ C ₃	1.28	0.56	0.43
	R ₃ C ₅	0.77	0.93	1.20	R ₂ C ₆	0.64	1.39	2.16
	R ₂ C ₆	0.64	1.39	2.16	R ₄ C ₄	0.96	0.69	0.72
	R ₅ C ₄	0.48	0.28	0.58	R ₄ C ₅	0.77	0.93	1.20
	R ₄ C ₅	0.38	0.35	0.90	R ₃ C ₆	0.32	0.46	1.44
Range.....		2.18	1.57	1.92		2.56	3.71	1.92
Low yields.....	R ₁ C ₁	15.40	11.10	0.72	R ₁ C ₁	15.40	11.10	0.72
	R ₂ C ₁	13.46	4.86	0.36	R ₂ C ₁	13.46	4.86	0.36
	R ₃ C ₁	11.55	2.78	0.24	R ₃ C ₁	11.55	2.78	0.24
	R ₆ C ₁	7.70	1.11	0.14	R ₂ C ₂	5.77	4.17	0.72
	R ₁ C ₂	6.74	9.72	1.44	R ₃ C ₂	4.81	2.32	0.48
	R ₁ C ₃	3.85	8.34	2.16	R ₆ C ₁	1.92	0.18	0.09
	R ₇ C ₁	3.85	0.40	0.10	R ₁ C ₆	0.96	4.17	4.32
	R ₈ C ₁	<i>1.92</i>	<i>0.18</i>	<i>0.09</i>	R ₇ C ₂	0.96	0.20	0.20
	R ₁ C ₈	0.24	1.39	5.76	R ₆ C ₃	<i>0.64</i>	<i>0.23</i>	<i>0.36</i>
Range.....		15.16	10.92	5.67		14.76	10.92	4.23
Entire series	Maximum	15.40	11.10	5.76				
	Minimum	0.24	0.18	0.09				
	Range....	15.16	10.92	5.67				

of the ratios Mg/Ca and Mg/K in the two series, the range in the values of these two ratios for the group of cultures producing high root yields being 2.18 and 1.75, respectively, in series A, and 2.56 and 3.71, respectively, in series B. The range value of the Ca/K ratio for the group of high-yielding cultures in each of the two series is 1.92.

The cultures R₅C₄ and R₃C₅, giving the highest yields in series A and B, respectively, agree in showing low values for the cation ratios characterizing

these cultures, but like the ratio ranges characterizing the groups of high-yielding cultures in the two series, the values of the corresponding ratios for the two cultures show considerable variations. Thus, the values of the three ratios Mg/Ca, Mg/K, and Ca/K for the culture (R_5C_4) giving the highest yield in series A, are 0.48, 0.28, and 0.58, respectively, and the corresponding ratio values for the culture (R_3C_5) producing the highest dry weight of roots in series B are 0.77, 0.93, and 1.20.

The group of nine cultures producing low yields of roots during the early period of development is characterized by the highest and lowest values of each of these cation ratios. The ranges in the magnitudes of these cation ratio values for this group of cultures are, therefore, coextensive with the corresponding ranges for the entire series. The group of nine low-yielding cultures for the late developmental period also shows very wide ranges in the values of the ratios Mg/Ca, and Ca/K, these ranges being 14.76 and 4.23, respectively. It embraces also the full range of the values of the Mg/K ratio.

From a study of the ion ratio data for high and for low yields of tops and of roots as given in tables 4 and 5, respectively, it appears that high yields of tops and of roots are, in general, associated with relatively low, but not the lowest, values of the three cation ratios. Low yields of tops and of roots, on the other hand, generally occur with solutions which are characterized by values of one or more of the three cation ratios which are either relatively high or relatively very low

D. Dry weights of seeds

The actual and the relative dry weights of seeds are presented in table 2 in connection with the corresponding data for tops and roots of the same series. The actual dry-weight values of seeds, as given in the table, represent the average yields from two similar series. The relative yield values were obtained in the same manner as were those of tops and of roots. The last column of table 2 gives the ratio values obtained by dividing the average actual dry weight values of tops by the corresponding values of seeds. These ratio values represent the yields of tops expressed in terms of the corresponding yields of seeds considered as 1.00.

The relative yields of seeds are graphically represented on the triangular diagram of figure 3, which corresponds to those of figures 1 and 2, representing in the same manner the relative yields of tops and of roots, respectively. It will be observed that the main area of low yields of seeds, including five of the nine cultures embraced within the range of low (0.71–0.92) dry weights, occupies a region bordering on the left margin of the diagram. Three smaller outlying areas of low yields also are indicated. The total range (1.31–1.68) of high yields of seeds is represented on the diagram by a single area occupying a central region at the base of the triangle and extending upward to the center, and to the right margin at culture R_3C_6 .

The lowest yield of seeds occurred with culture R_3C_1 , and the highest dry weight was produced by culture R_3C_5 . The average yield from this culture was 68 per cent higher than the corresponding yield from culture R_1C_1 . The total range of the average dry weights of seeds extended from 0.71 to 1.68.

A comparison of the diagram of figure 3 with those representing the yields of tops and of roots of the same series (series B, fig. 1 and 2, respectively), shows a marked degree of similarity between the diagrams with respect to the distribution of the areas of high and also of low yields. Five of the nine cultures shown in the area of high yields of seed are included in the area of high top yields, and four are also included in the area of high yields of roots. The maximum yields of tops, of roots, and of seeds were produced by the same culture, R_3C_5 , but no such correlation is shown for minimum yields. The diagrams representing the three kinds of yields agree, however, in showing the main areas of low dry weights to occupy somewhat corresponding regions on the left margins of the diagrams. It thus appears that the yields of tops, of roots, and of seeds vary in a somewhat similar manner with respect to the variations in the proportions of the three salts in the solutions supplied to the sand cultures. The plants of each of the 36 cultures of this series produced an abundance of large, fairly uniform, and well filled seeds. From an inspection of the last column of table 1, giving the yields of tops in terms of the corresponding yields of seeds, considered as unity, it will be observed that these ratio values for eight cultures lie between 3.0 and 4.0, the values for twenty-three cultures lie between 2.0 and 3.0, and for five cultures the values of the ratios are between 1.0 and 2.0. The ratio of the average yield of tops to the average yield of seeds for the entire series is 2.27. This indicates that the average yield of tops for this series is only 2.27 times the corresponding yield of seeds.

A comparison of the diagram of figures 3 with the diagram graphically representing the yields of seeds from the corresponding series of solution cultures previously carried out, shows that the two corresponding diagrams are in partial agreement with respect to the distribution of the areas of high and low yields of seeds. Five of the nine high-yielding cultures in the present sand culture series are also indicated as producing high dry weights of seeds in the solution cultures, but the maximum yields of seeds did not occur with corresponding cultures of the two series. The highest yield of seeds in the sand cultures occurred with culture R_3C_5 , which produced a medium yield in solution culture. Culture R_3C_3 , which gave the maximum yield of seeds in solution culture, produced a medium yield in the present series of sand cultures. It is to be noted also that culture R_4C_3 , which gave a high yield of seeds in sand culture, produced a low yield in solution culture, while culture R_5C_4 , which is indicated as producing a high yield in solution culture, gave a low yield in sand culture. It may be said, however, that the two series show a marked similarity with respect to the position on the triangular diagrams occupied by the main areas of high and of low yields of seeds.

II. Effect of the sand medium upon the physiological properties of the solutions

As previously stated, the maximum yields of buckwheat tops obtained during the early developmental period, from the present series of sand cultures, and from the corresponding series of solution cultures previously carried out, were produced by the same set of salt proportions. These were the salt proportions of culture R_4C_2 . The corresponding series of sand and solution cultures conducted during the late period of development also agreed in showing their highest yields of tops for the same set of salt proportions, these being the salt proportions characterizing the culture R_3C_5 . It thus appears that the physiological properties of the solutions producing maximum yields of buckwheat tops are not altered to any great extent when these solutions are introduced into the sand here employed, and in the manner described.

It is possible, of course, that solutions such as were here employed may undergo, not only a reduction in the total concentration, but also a change in the relative proportions of the constituent salts and ions, as the result of contact with the solid sand particles. It should again be emphasized, however, that in the present experiments, the sand of each culture was flooded with the nutrient solution, which was then drawn off, leaving the culture with a fixed solution content (15 per cent of the weight of the air-dry sand), after which two more portions of the solution (250 cc. to each portion) were passed through the sand cultures before the culture pots were sealed and the time period of the experiment actually begun. With such treatment and with subsequent renewal of the solutions every third day, it appears reasonable to suppose that equilibrium would soon become established with respect to the adsorptive capacity of the sand, after which the solution should suffer no further alteration from this factor, either in total concentration or in the relative proportions of the salts and ions, excepting as the adsorptive action of the sand might change with changes in temperature.

An attempt was here made to determine the influence of the sand upon the total concentration of the various solutions in the sand cultures employed, both at the beginning and at the end of an experimental period of 4 weeks' duration. For these tests the cryoscopic method was employed. A series of 36 sand cultures was prepared as already described. After the seedlings had been transplanted to the culture pots, the sand cultures reduced to the desired moisture content (15 per cent on the air-dry weight basis), and the culture pots sealed, these were allowed to stand in the greenhouse for 24 hours. A sufficient quantity of solution was then withdrawn from each sand culture, by the method already described, to be tested for the lowering of the freezing point. The solution withdrawn from each culture was replaced by an equal quantity of new solution. The cultures were then continued with renewal of solutions every third or fourth day. At the end of the growth period the solutions in the sand cultures were renewed in the usual way and the cultures were again allowed to stand for 24 hours. The cultures were then weighed

and the water lost by transpiration during the preceding 24 hours was restored by the addition of distilled water. After an interval of from 20 to 30 minutes to allow the water films to come into partial equilibrium, a small quantity of solution sufficient for the test of the lowering of the freezing point was withdrawn from each sand culture, after which the plants were harvested in the usual manner.

In table 6 are presented the results of the freezing-point determinations of the solutions withdrawn from the sand cultures supplied with the different solutions of the optimal 3-salt series employed in these studies. The solution or culture numbers referring to the triangular diagram are given in the first column of the table, which is divided into two vertical sections of three columns each. The first section presents the actual depressions of the freezing point (after corrections were made for undercooling), the osmotic concentration value at 25°C., and the variations from the original calculated osmotic concentration value of 1.75 atmospheres, for each of the 36 different solutions tested at the beginning of the growth period. The last section gives the corresponding data for the tests made at the end of the growth period. Each of the data in this table represents the average of two or more tests.

It will be observed that the osmotic-concentration values of the solutions extracted from the sand cultures at the beginning of the growth period are, with the single exception of solution R_7C_1 , in very close agreement with the calculated value of the original solutions. The greatest deviation above 1.75 atmospheres is 13.15 per cent (solution from culture R_7C_1), and the greatest below this calculated value is 4.75 per cent. The average osmotic concentration value for the entire series is 1.753 atmospheres, which represents a deviation from the original value of only 0.17 per cent. The results of the tests made at the end of the growth period show a somewhat wider variation from the original concentration value than do those of the tests made at the beginning of the growth period, the greatest deviation above the concentration value of the original solutions being 9.14 per cent, while the greatest deviation below this value is 14.28 per cent. However, the osmotic concentration values of these solutions (with the exception, perhaps, of those from cultures R_2C_4 , R_3C_2 , R_7C_1 , and R_7C_2) show as close agreement with the calculated value of the original solutions as might be expected, considering the numerous manipulations involved in the repeated renewal of solutions during a period of 4 weeks, and the chance of cumulative slight errors resulting therefrom. The average osmotic concentration value for the entire series is 1.72 atmospheres which represents a minus deviation from the calculated value of only 1.71 per cent. The majority of the solutions of this series show minus deviations from the calculated value, but many also show plus deviations, so that little significance can be attached to the comparatively slight deviations from the calculated concentration value, especially since there is no regularity in the manner in which the deviations occur.

Variations in the total concentrations such as were here observed, are scarcely sufficient to produce any marked changes in the growth rates, especially since these concentrations lie well within the range of optimal growth for these

TABLE 6
Concentration data of solutions extracted from sand cultures at the beginning and at the end of a 4-week growth period

CULTURE NUMBER	BEGINNING OF GROWTH PERIOD			END OF GROWTH PERIOD		
	Depression of the freezing point	Osmotic-concentration value at 25°C.	Variation from calculated osmotic-concentration value (1.75 atm.)	Depression of the freezing point	Osmotic-concentration value at 25°C.	Variation from calculated osmotic-concentration value (1.75 atm.)
	°C.	atm.	per cent	°C.	atm.	per cent
R ₁ C ₁	0.134	1.76	0.57	0.135	1.77	1.14
C ₂	0.132	1.74	-0.57	0.132	1.74	-0.57
C ₃	0.130	1.72	-1.71	0.132	1.74	-0.57
C ₄	0.133	1.75	0.00	0.140	1.84	5.14
C ₅	0.134	1.76	0.57	0.123	1.62	-7.43
C ₆	0.131	1.72	-1.71	0.140	1.84	5.14
C ₇	0.131	1.72	-1.71	0.123	1.62	-7.43
C ₈	0.132	1.74	-0.57	0.142	1.86	6.28
R ₂ C ₁	0.133	1.75	0.00	0.138	1.82	4.00
C ₂	0.126	1.67	-4.57	0.140	1.84	5.14
C ₃	0.134	1.76	0.57	0.140	1.84	5.14
C ₄	0.130	1.72	-1.71	0.145	1.91	9.14
C ₅	0.133	1.75	0.00	0.132	1.74	-0.57
C ₆	0.135	1.77	1.14	0.126	1.67	-4.57
C ₇	0.134	1.76	0.57	0.132	1.74	-0.57
R ₃ C ₁	0.134	1.76	0.57	0.135	1.78	1.71
C ₂	0.136	1.78	1.71	0.116	1.53	-12.58
C ₃	0.142	1.86	6.28	0.126	1.67	-4.57
C ₄	0.136	1.79	2.29	0.126	1.67	-4.57
C ₅	0.133	1.75	0.00	0.130	1.72	-1.71
C ₆	0.130	1.72	-1.71	0.121	1.60	-8.58
R ₄ C ₁	0.133	1.75	0.00	0.122	1.61	-8.28
C ₂	0.131	1.72	-1.71	0.132	1.74	-0.57
C ₃	0.137	1.80	2.86	0.133	1.75	0.00
C ₄	0.144	1.89	8.00	0.132	1.74	-0.57
C ₅	0.131	1.72	-1.71	0.121	1.60	-8.58
R ₅ C ₁	0.134	1.76	0.57	0.133	1.75	0.00
C ₂	0.132	1.74	-0.57	0.132	1.74	-0.57
C ₃	0.135	1.77	1.14	0.132	1.74	-0.57
C ₄	0.132	1.74	-0.57	0.135	1.78	1.71
R ₆ C ₁	0.132	1.74	-0.57	0.124	1.63	-6.86
C ₂	0.133	1.75	0.00	0.140	1.84	5.14
C ₃	0.133	1.75	0.00	0.129	1.70	-2.86
R ₇ C ₁	0.151	1.98	13.15	0.114	1.50	-14.28
C ₂	0.133	1.75	0.00	0.114	1.50	-14.28
R ₈ C ₁	0.129	1.70	-2.86	0.129	1.70	-2.86

plants, so that the results of these tests are in entire accord with the behavior of the plants in solution cultures and in the corresponding sand cultures, as this behavior was judged by the criterion of dry-top yields.

III. Transpiration and water requirement

Since transpiration may be regarded as a valuable indicator of the general health and vigor of plants, it was deemed worth while to compare the relative amounts of water lost from the various cultures during their growth period with the data of the other plant measurements. From the relation between the amounts of water lost by transpiration and the dry-weight yields of tops, roots, and seeds, may be derived also the ratios representing the amount of water lost for each single gram of dry plant substance produced. These ratios of transpiration to yields represent the water requirements of the plants. Because of the importance of this criterion of plant growth, and for the sake of completeness, it seemed desirable also to compare these derived data with the direct quantitative plant measurements.

The data of transpiration and water requirements are presented in table 7 in three sections. The first section gives the relative amounts of water loss from the cultures of the two series representing the two different developmental periods here considered. This is followed by the section giving the water requirements of tops and of roots for series A. The last section presents the corresponding data for series B, and also the water requirements of seeds for this series. The various data for each culture are expressed in terms of the corresponding data for culture R_1C_1 in the respective columns. In each column the actual value for this culture is given in parentheses just below the relative value.

The average data of table 7 were plotted on triangular diagrams in the same manner as were the yields of tops, roots, and seeds, and the corresponding diagrams of the two different series thus obtained were compared with each other and also with the corresponding yield diagrams already given (figs. 1, 2 and 3). The various diagrams graphically representing the data of table 7 are not here presented, but the main points of interest brought out by these comparisons will be given in brief.

A. Relation of transpiration to yields

The main areas representing high and low water loss on the transpiration diagram of series A occupy positions corresponding very closely with those occupied by the main areas of high and low yields, respectively, of tops and of roots on the yield diagrams. The highest total amount of water loss from a single culture of this series, however, did not occur with the same culture giving the maximum yield of tops, nor with that producing the highest yield of roots. In series B the agreement between the transpiration diagram and the corresponding yield diagrams of tops and of roots, with respect to the

main areas of both high and low yields, is even more pronounced than it is in series A. The maximum yield of tops and of roots and the greatest amount

TABLE 7

Data of transpiration and water requirement; series A grown to the flowering stage, series B grown from the flowering stage to maturity in sand cultures supplied with 3-salt solutions

CULTURE NUMBER	TRANSPIRATION		WATER REQUIREMENT				
	Series A	Series B	Series A		Series B		
			Tops	Roots	Tops	Roots	Seeds
R ₁ C ₁	1.00 (502)	1.00 (2384)	1.00 (254)	1.00 (1716)	1.00 (485)	1.00 (4599)	1.00 (794)
C ₂	1.21	1.59	0.83	1.21	1.25	1.45	1.32
C ₃	1.31	1.68	0.89	1.50	1.10	1.01	1.23
C ₄	1.36	1.81	0.83	1.26	1.07	1.17	1.16
C ₅	1.42	1.81	0.89	1.29	0.98	1.12	1.21
C ₆	1.49	1.64	0.90	1.28	1.04	1.22	1.50
C ₇	1.40	1.60	0.77	1.26	0.93	0.98	1.66
C ₈	1.35	1.66	0.91	1.66	0.89	1.22	2.04
R ₂ C ₁	1.06	1.49	1.00	1.35	1.13	0.97	1.96
C ₂	1.53	1.32	0.85	1.19	1.01	1.15	2.14
C ₃	1.59	1.62	0.86	1.35	0.95	0.90	2.17
C ₄	1.41	1.73	0.80	1.32	0.93	0.86	1.41
C ₅	1.68	1.89	0.92	1.26	0.99	0.85	1.38
C ₆	1.86	1.79	0.93	1.45	0.93	0.91	1.36
C ₇	1.48	1.59	1.04	1.35	0.89	1.05	1.44
R ₃ C ₁	1.26	1.60	1.01	1.30	0.96	1.20	2.98
C ₂	1.49	1.86	0.89	1.39	1.01	1.65	1.61
C ₃	1.62	1.38	0.88	1.10	0.73	0.62	1.40
C ₄	1.59	1.72	0.89	1.42	0.85	0.85	1.25
C ₅	1.55	2.03	0.86	1.43	0.78	0.78	1.17
C ₆	1.49	1.84	0.93	1.36	0.94	0.89	1.26
R ₄ C ₁	1.39	1.46	0.98	1.16	1.04	1.09	1.90
C ₂	1.72	1.77	0.76	1.33	1.07	0.88	1.40
C ₃	1.61	1.83	0.80	1.26	1.03	0.99	1.35
C ₄	1.71	1.81	0.89	1.23	0.88	0.77	1.77
C ₅	1.69	1.61	0.89	1.28	1.15	1.06	1.98
R ₅ C ₁	1.26	1.69	1.10	1.55	1.47	0.96	1.40
C ₂	1.33	1.77	0.89	1.35	1.11	0.87	1.55
C ₃	1.74	1.85	0.87	1.63	1.01	0.87	1.80
C ₄	1.50	1.61	0.83	0.99	0.85	0.94	1.78
R ₆ C ₁	1.21	1.44	0.99	1.20	1.26	0.93	2.07
C ₂	1.48	1.71	0.84	1.07	1.04	0.88	1.55
C ₃	1.51	1.75	0.85	1.23	1.04	1.61	1.64
R ₇ C ₁	1.20	1.64	0.97	1.22	1.27	1.32	1.54
C ₂	1.34	1.64	0.90	1.26	1.09	1.06	1.59
R ₈ C ₁	1.24	1.65	0.95	1.26	1.32	1.30	1.70
K	1.50	1.76	0.92	1.36	0.97	0.85	1.30
T	1.64	1.72	0.91	1.23	1.01	1.05	2.03

of transpirational water loss from any single culture here occurred with the same culture, R_3C_5 . The lowest yield of tops and the smallest amount of water loss is shown for culture R_1C_1 .

From these considerations it is clear that high transpiration, in general, is associated with high yields of tops and of roots, and low transpiration with low yields, an observation which is in entire accord with what has already been found in the study of buckwheat in solution cultures corresponding to the present study of these plants in sand cultures.

A comparison of the transpiration diagram of series A with the corresponding diagram of series B, brings out the fact that there is no agreement between the two diagrams with respect to the areas of high transpiration values. The two series agree, however, in showing the main regions of low transpiration as bordering on the left margins of the diagrams. It thus appears that the relation between the various salt proportions and transpiration, with respect to the two different periods of development, is much the same as is the relation between the salt proportions and the yields of tops and of roots.

B. Relation of water requirements to yields

A comparison of the water-requirement diagrams with the corresponding yield diagrams, shows that the relations between water requirement of tops and the dry-weight yields of tops are very well defined in each of the two series here considered. On the diagram representing the water requirements of tops of series A, the areas of high values agree absolutely with the areas of low values on the corresponding diagram of top yields, while the regions of low water requirements agree in a general way with those of high top yields. There is no detailed relation, however, between the water requirements of roots and root yields in this series.

On the diagrams of series B, the regions of low water requirements correspond very closely with those of high top yields, while the areas of high water requirements and low top yields show equally good agreement. There is a marked tendency also toward the same relations between the water requirements of roots and root yields in this series, although the agreements are not so exact as they are in the case of the water requirements of tops and top yields.

A comparison of the water requirement diagram for seeds with the corresponding yield diagram shows the areas representing low water requirements to correspond very closely with those of high seed yield, while the regions of high water requirements of seeds are in close agreement with those of low seed yields. Thus, with the sand cultures of the present study, as with the corresponding solution cultures of the earlier work, low water requirements are associated with high yields of tops, roots, and seeds, and high water requirements correspond to low yields.

From a comparison of the corresponding diagrams representing the water

requirements of the two different series, it is clear that there is as little correlation between the water requirements of the young plants of series A and the older ones of series B as there is between the dry-weight yields, either of tops or of roots, of the two different series, or between the transpirational water loss from the cultures of series A and those of series B. Thus, by whatever set of measurements the relation between the growth rates and the proportions of the salts in the media is judged, this relation is found to be markedly different for the two different developmental periods.

In the earlier work with solution cultures corresponding to the present series of sand cultures, it was emphasized that the changes in the physiological requirements of these plants, with respect to the proportions of the salts in the nutritive media might be a gradual process extending over a comparatively long interval of time, involving perhaps the entire life period of the plants. On the other hand, it was pointed out that the change in salt requirements of the plants may take place comparatively rapidly with the marked changes which occur within the plants during the blossoming stage, when the vegetative processes become less active and the reproductive and seed-forming processes begin.

In some recent work by McCall (6), the active life period of the wheat plant was divided to cover three stages in its development: the first 30-day period, the second 30-day period, and finally the period extending from the close of the second 30 days to the maturity of the plant. McCall was able to show that the mineral requirements of the wheat plant during the first and the second 30-day periods were substantially the same, but the salt proportions producing high and low yields during the third growth period were markedly different from those giving corresponding yields during the first and second 30-day growth periods. While this does not directly apply to the salt requirements of the buckwheat plants here employed, it strongly suggests the possibility that the change in physiological requirements of these plants may take place during the flowering stage or during the period extending from the flowering stage to the maturity of the plants.

SUMMARY

The preceding pages present the results of a comparative study of the salt requirements of buckwheat plants during two different developmental periods. The plants were grown in sand cultures supplied with nutrient solutions of the same initial total osmotic concentration value of 1.75 atmospheres, but differing in the proportions of the component salts. The series of solutions supplied to the sand cultures comprised 36 different sets of salt proportions of the three salts KH_2PO_4 , $\text{Ca}(\text{NO}_3)_2$, and MgSO_4 .

The results obtained from the plants grown during the first 4 weeks after germination, in sand cultures supplied with nutrient solutions, were compared with those obtained from older plants grown during the period of development

between the flowering stage and maturity, in sand cultures supplied with the same solutions. The main facts brought out by this comparative study are briefly summarized as follows:

1. The highest yield of buckwheat tops obtained in a period of 4 weeks directly following germination occurred with the sand culture supplied with a solution having the following salt proportions: KH_2PO_4 , 0.0144 m.; $\text{Ca}(\text{NO}_3)_2$, 0.0052 m.; and MgSO_4 , 0.0200 m. The highest yield of tops, of roots, and of seeds was obtained, during the second developmental period, from a sand culture supplied with a solution having the salt proportions of KH_2PO_4 , 0.0108 m.; $\text{Ca}(\text{NO}_3)_2$, 0.0130 m.; and MgSO_4 , 0.0100 m. Thus the maximum yields were produced during the late developmental period in a sand culture furnished with a solution characterized by having a lower proportion of mono-potassium phosphate, a much higher proportion of calcium nitrate and a much lower one of magnesium sulfate than had the solution supplied to the sand culture giving the highest yield of tops during the early period of development.

2. The salt proportions of the solution in the sand culture of the present series producing the maximum yield of tops during the early developmental period, and those giving the highest yields of tops and of roots during the late period of development, are in exact agreement with those giving maximum yields of tops and of roots in the corresponding series of solution cultures previously carried out.

3. Under the conditions of these experiments the physiological properties of the nutrient solutions, as these affect the growth of the plants, are not altered to any marked extent when the solutions are added to the sand cultures.

4. High yields of tops and of roots are, in general, associated with relatively low values—but not the lowest values—of the three cation ratios Mg/Ca , Mg/K , and Ca/K . The values of these ratios characterizing the solutions supplied to the sand cultures, show pronounced differences for the cultures giving maximum yields of tops, and maximum yields of roots, and also for those giving minimum yields of roots, during the two different developmental periods of growth.

5. High transpirational water loss is associated with high yields of tops and of roots, and low transpiration with low yields.

6. For each of the two developmental periods of growth, high water requirement is, in general, associated with low yields of tops and of roots, and low water requirement with high yields.

7. The relation of the growth rates of the buckwheat plants to the variations in the osmotic proportions of the solutions supplied to the sand culture is markedly different for the two different developmental periods of growth, whether this relation is judged by the criterion of tops or of roots, by that of transpiration, or by that of the water requirements of tops or of roots.

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