U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 113.

B. T. GALLOWAY, *Chief of Bureau.*

THE COMPARATIVE TOLERANCE OF VARIOUS PLANTS FOR THE SALTS COMMON IN ALKALI SOILS.

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ISSUED OCTOBER 25, 1907.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1907.

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ALKALI AND DROUGHT RESISTANT PLANT BREEDING INVESTIGATIONS.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., July 15, 1907.

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 113 of the series of this Bureau the accompanying technical paper, entitled "The Comparative Tolerance of Various Plants for the Salts Common in Alkali Soils," by T. H. Kearney and L. L. Harter.

The results of this work show clearly that different genera and species of plants differ greatly in their power of resistance to a given mixture of alkali salts and that marked differences in resistance also exist between different individuals of the same strain or variety, proving, therefore, that there is a good opportunity for increasing this quality by the artificial selection of resistant strains. The work also shows clearly that a strain made resistant to one combination of salts may not be resistant to another combination. The results are therefore important to those engaged in the selection and improvement of crops for alkali soils.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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THE COMPARATIVE TOLERANCE OF VARIOUS PLANTS FOR THE SALTS COMMON IN ALKALI SOILS.

INTRODUCTION.

In Report No. 71 of the Department of Agriculture[a] an account was given of the results of experiments upon the toxicity of certain salts of magnesium and sodium to young seedlings of the white lupine and of alfalfa. It was shown that these salts differ greatly in their toxicity when allowed to act upon the plants in pure solutions (i. e., of a single salt), but that the presence of a second salt, notably calcium sulphate, not only greatly increases the endurable concentration of the more toxic salt, but tends to equalize the toxicity of the different salts. Experiments, the results of which have not hitherto been published in full,[b] were afterwards made with maize, and it was found that not only were the critical concentrations of the same salts very different from those previously worked out for the white lupine, but the order of toxicity of the various salts also differed widely. The results obtained by Harter[c] with nine varieties of wheat show that not only are the critical concentrations for this plant different from those previously established for the white lupine and for maize, but that inside the limits of a species there can be much difference between different varieties in their power of resistance to toxic action.

Since the publication of this last paper similar experiments have been made with four varieties of sorghum (*Andropogon sorghum*), two varieties of oats (*Avena sativa*), two species of cotton (*Gossypium barbadense* and *G. hirsutum*), and sugar beets (*Beta vulgaris*). A majority of the more important field crop plants grown in parts of the United States where alkali soils occur are thus represented in the whole series of experiments.[d]

[a] Some Mutual Relations Between Alkali Soils and Vegetation, 1902.

[b] Although referred to in a brief note in Science, n. s., vol. 17, p. 386, 1903.

[c] Bul. 79, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1905.

[d] The white lupine was selected for the first experiments, not because it is of any importance as a crop plant in this country, but because of the ease with which it is handled in water-culture experiments.

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The results have established the fact that different genera and species differ greatly in their power of resistance to the salts of magnesium and sodium that are common in so-called alkali soils, and that furthermore different varieties, or even mere agricultural strains of the same species, possess marked differences in this respect. In mixed solutions, especially in the presence of a salt of calcium, these differences are much less pronounced, but still exist in such a degree as to leave no escape from the conclusion that some species and varieties of plants are better adapted than others to growing in soils containing relatively large amounts of these salts. Since very marked differences in tolerance exist between different individuals of the same strain or variety, there is obviously an opportunity for an increase of this quality by artificial selection.

In the present paper the results of experiments with single (pure) solutions in their effect upon maize, sorghum (four varieties), oats (two varieties), cotton (two species), and sugar beets are first described. The resistance to pure solutions of these plants and of the white lupine, alfalfa, and wheat are next compared. The effect of an excess of calcium sulphate in neutralizing the toxicity of the magnesium and sodium salts upon each of the plant species above mentioned, and finally that of amounts of calcium sulphate smaller than an excess in counteracting the toxic effect of these salts upon the white lupine and upon sorghum are then treated.

It should be emphasized that the results of these water-culture experiments with pure solutions of a single salt or of two salts are not to be directly compared with the results of observations made upon plants growing in natural "alkali" soils. In the latter case we have always to deal with a mixture of several salts, and, moreover, the presence of the soil itself introduces physical factors that modify in various ways the effect of the solution upon plants. In these laboratory experiments the problem was purposely simplified by omitting the soil, thus permitting us to ascertain directly the varying toxic effect upon different plants of some of the principal "alkali" salts as a necessary preliminary to the more complex problem of their toxicity in the presence of the soil itself. In the experiments with mixed solutions a step is taken in the direction of this greater complexity, and it is noteworthy that the results obtained are in this case more nearly comparable with the relations obtaining in nature than are those with pure solutions. Experiments are now in progress in which cultures in sand watered with the extracts from natural alkali soils and with solutions of salts made up to imitate the alkali soil extracts, as well as in the natural alkali soils themselves, are substituted for the water cultures used in the experiments here described.

EXPERIMENTAL METHODS.

The methods used were described at considerable length in two previous publications upon this subject.[a] It suffices here to state that the effect upon the rapidly elongating portion (10 to 20 mm.) of the tips of the radicles of young seedlings was alone studied, inability to further elongate when transferred to pure water after twenty-four hours' exposure to the salt solution being taken as an indication that the concentration used was fatal to the root tips. The strength of solution which permits the root tips of about half the total number of seedlings used to survive this test is taken as the critical concentration.[b] The results are stated throughout in terms of fractions of normal solutions.

RESULTS WITH PURE SOLUTIONS.

RESULTS WITH MAIZE (ZEA MAYS).

TABLE I.—*Limits of endurance of maize seedlings of salts of sodium and magnesium.*

Salts used.	Critical concentrations.	Salts used.	Critical concentrations.
Sodium carbonate	0.015 normal	Sodium bicarbonate	0.05 normal
Sodium chlorid	.04 normal	Mag esium chlorid	.08 normal
Sodium sulphate	.05 normal	Magnesium sulphate	.25 normal

RESULTS WITH COTTON (GOSSYPIUM).

The Jannovitch Egyptian variety of cotton (*Gossypium barbadense*) and the Griffin Upland variety of cotton (*G. hirsutum*) were selected for these experiments.

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[a] Kearney and Cameron, in Report No. 71, U. S. Dept. of Agriculture, pp. 13 to 18; and Harter, in Bul. 79, Bureau of Plant Industry, U. S. Dept. of Agriculture, pp. 16 to 23.

[b] The objection has been made to this method that the period of growth is too short and that the effect upon the root tip does not necessarily represent the effect upon the plant as a whole. Since, however, the purpose of these experiments is merely to obtain a simple and ready means of comparison of the toxicity of different salts to different plants under identical conditions and not a measure of the absolute limit of concentration that will permit the growth to maturity of plants of a given species, it is believed that the method used answers every purpose of this investigation. When the period is extended and the effect upon the whole plant is taken into consideration so many disturbing factors are introduced that reliable results become difficult if not impossible. Furthermore, since the conditions of these experiments are confessedly artificial—pure salt solutions rarely, if ever, occurring in nature—little would be gained by working out the limits of endurance for the entire plant during a long period of growth. In the experiments with soil cultures now in progress the effect of the salts upon the growth of the whole plant during a period of several weeks is taken into account.

TABLE II.—*Limits of endurance of cotton seedlings of salts of magnesium and sodium.*

Salts used.	Critical concentrations.	
	Gossypium barbadense.	Gossypium hirsutum.
Magnesium sulphate	0.000312 normal	0.000312 normal
Magnesium chlorid	.0004 normal	.000312 normal
Sodium carbonate	.005 normal	.0025 normal
Sodium sulphate	.005 normal	.005 normal
Sodium bicarbonate	.00625 normal	.00375 normal
Sodium chlorid	.00625 normal	.005625 normal

The most marked difference in resistance between the two species of Gossypium appears in the presence of sodium carbonate and sodium bicarbonate. Egyptian cotton (*Gossypium barbadense*) can endure twice as concentrated a solution of the carbonate and nearly twice as concentrated a solution of the bicarbonate as can Upland cotton (*G. hirsutum*). In resistance to magnesium chlorid and to sodium chlorid, also, *Gossypium barbadense* is slightly superior to *G. hirsutum*.

RESULTS WITH SORGHUM (ANDROPOGON SORGHUM).

Four different varieties of *Andropogon sorghum*, designated by the popular names of the varieties, were tested.

TABLE III.—*Limits of endurance of sorghum seedlings of salts of magnesium and sodium.*

Salts used.	Critical concentrations.			
	Early Amber.	Dwarf Milo.	Edra.	Dagdi Juar.
Magnesium chlorid	0.00625 normal	0.00375 normal	0.003 normal	0.00125 normal
Magnesium sulphate	.0085 normal	.00625 normal	.00625 normal	.00375 normal
Sodium carbonate	.00625 normal	.0075 normal	.007 normal	.00625 normal
Sodium bicarbonate	.009 normal	.0125 normal	.01 normal	.00875 normal
Sodium sulphate	.015 normal	.013 normal	.0125 normal	.0125 normal
Sodium chlorid	.018 normal	.014 normal	.015 normal	.015 normal

The difference in toxicity between sodium chlorid and sodium sulphate is hardly appreciable in the case of this plant. In the presence of magnesium chlorid there is more difference in resistance between the different varieties than in the presence of magnesium sulphate.

All except the Early Amber variety can endure a greater concentration of sodium carbonate than of magnesium sulphate, and with this exception the order of toxicity of the different salts is that given in the table.

The Dwarf Milo variety of sorghum is on the whole less resistant to the toxic influences of the various salts than the Early Amber. Magnesium chlorid brings out the most noticeable difference in this respect, the Early Amber showing as much resistance to a concentration of 0.00625 normal of this salt as the Dwarf Milo does to 0.00375 normal. To sodium bicarbonate the Dwarf Milo is more resistant than the Early Amber. To the other salts the two varieties are almost equally resistant.

The Edra variety is slightly less resistant than the preceding variety. It will be noticed that this variety, as well as the Dwarf Milo, can endure a greater concentration of sodium bicarbonate than the Early Amber, although the latter is the variety that is most resistant to most of the salts. Of magnesium chlorid a concentration of 0.00625 normal is critical for the Early Amber variety, which is more than twice the concentration that is critical for the Edra variety, and five times that which is critical for the Dagdi Juar variety. The last is decidedly the most sensitive of the four varieties. The Edra is somewhat more resistant than the Dwarf Milo to sodium chlorid, but the variation in resistance to this salt, as well as to sodium sulphate, is very slight with all the varieties.

In the case of *Andropogon sorghum* as in that of Triticum the greatest difference in resistance among the different varieties is shown in the presence of the more harmful salts. To the less harmful salts—for example, the chlorid and sulphate of sodium—there is less variation in resistance.

RESULTS WITH OATS (AVENA SATIVA).

TABLE IV.—*Limits of endurance of oat seedlings of salts of magnesium and sodium.*

Salts used.	Critical concentrations.	
	Red Algerian.	Culbertson.
Magnesium sulphate	0.001875 normal	0.000625 normal
Magnesium chlorid	.001875 normal	.0005 normal
Sodium carbonate	.00625 normal	.0075 normal
Sodium bicarbonate	.0075 normal	.009 normal
Sodium sulphate	.0175 normal	.015 normal
Sodium chlorid	.02 normal	.015 normal

The Red Algerian variety of *Avena sativa* can endure a concentration of magnesium sulphate three times as great as that which is critical for the Culbertson variety. There is about the same amount of difference in resistance to magnesium chlorid, the Red Algerian being again the more resistant. The Algerian variety is more resistant than the Culbertson to every salt except two (sodium carbonate and bicarbonate), and in these cases the difference is but slight. It is interesting to note that the former variety, which came originally from Algeria, where it is said to be grown successfully in soils containing a considerable amount of harmful salts, shows also a greater power of resistance to salts in pure solutions.

RESULTS WITH SUGAR BEETS (BETA VULGARIS).

The "Original Kleinwanzleben" strain of the sugar beet was selected for use in these experiments.

TABLE V.—*Limits of endurance of sugar-beet seedlings of salts of magnesium and sodium.*

Salts used.	Critical concentration.	Salts used.	Critical concentration.
Magnesium sulphate	0.0005 normal	Sodium bicarbonate	0.0075 normal
Magnesium chlorid	.0005 normal	Sodium sulphate	.00875 normal
Sodium carbonate	.00625 normal	Sodium chlorid	.025 normal

To the sugar beet sodium sulphate in pure solution is three times as toxic as sodium chlorid and only a little less toxic than sodium carbonate. The two magnesium salts are more than ten times as toxic as is sodium carbonate.

COMPARISON OF RESULTS WITH EIGHT SPECIES IN PURE SOLUTIONS.

In Table VI are brought together the results with pure solutions for all the species of plants so far investigated, the figures given being in each case the fraction of a normal solution representing the concentration of solution that allows the root tips of about one-half the total number of seedlings tested to retain their capability of further elongation after twenty-four hours of exposure to the solution.

TABLE VI.—*Critical concentrations of pure solutions for eight species of plants.*

Salts used.	Plants tested.								
	Lupinus albus (white lupine).*		Medicago sativa (alfalfa).	Triticum vulgare (wheat).	Zea mays (maize).	Andropogon sorghum (sorghum).	Avena sativa (oats).	Gossypium barbadense (cotton).	Beta vulgaris (beet).
	Series 1.	Series 2.							
Magnesium sulphate	0.00125	0.007	±0.001	0.005	0.25	0.00375	0.001875	0.000312	0.0005
Magnesium chlorid	.0025	.0075	± .002	.005	.08	.00125	.001875	.0004	.0005
Sodium carbonate	.005	.0125	....	.0125	.015	.00675	.00625	.005	.00625
Sodium sulphate	.0075	.04	....	.04	.05	.0125	.0175	.005	.00875
Sodium chlorid	.02	.045	....	.045	.04	.015	.02	.00625	.025
Sodium bicarbonate	.02	.03	....	.025	.05	.00875	.0075	.00625	.0075

*The experiments with *Lupinus albus* by Kearney and Cameron that were described in Report No. 71 of the United States Department of Agriculture, and of which the results are given in the column headed "Series 1" of Table VI, were repeated two years later by Harter, using a fresh lot of white lupine seed which, like the first, was obtained from Vilmorin, Andrieu & Co. in Paris. The critical concentrations worked out in this second series of experiments (as shown in the table) are much higher than those obtained in the first experiments. That this was largely due to the use of fresher seed was proved by repeating the experiments a third time, using seed of the same importation as that in series 2, but a year older. In this third series of experiments the results agreed more closely with series 1 than with series 2, the critical concentrations having been determined as follows: Magnesium sulphate, 0.002 normal; magnesium chlorid, 0 0025 normal; sodium carbonate, 0.0125 normal; sodium sulphate, 0.02 normal; sodium chlorid, 0.0175 normal; sodium bicarbonate, 0.015 normal. The order of toxicity of the different salts is very nearly the same in the three series, the principal difference being that in the second and third sodium chlorid is slightly more toxic than sodium sulphate, and sodium bicarbonate than sodium sulphate and chlorid. It is noteworthy that the critical concentrations in mixed solutions (containing calcium sulphate) were practically the same with the second lot of seed, even when fresh, as with the first, notwithstanding the great differences in the resistance of the two lots to pure solutions (see the second note to table on page 15).

The limits for *Medicago sativa* in pure solutions were worked out for the two magnesium salts alone, and with these the results are only approximate. Those for *Triticum vulgare* were obtained by Harter with the Chul variety of wheat. In the case of *Andropogon sorghum* the limits for the Dagdi Juar variety are given; in that of *Avena sativa*, those for the Red Algerian variety of oats; in that of *Gossypium barbadense*, those for the Jannovitch Egyptian variety of cotton, and in that of *Beta vulgaris*, those for the Original Kleinwanzleben strain of sugar beets.

A glance at Table VI shows that not only do the different species differ vastly in the absolute degree of their resistance to the toxic action of these pure solutions, but the order of toxicity of the several salts varies considerably with respect to different species. For convenience of comparison, the order of toxicity of the six salts to each of the eight species is stated in Table VII.

TABLE VII.—*Order of toxicity of the different salts to each plant.*

Lupinus albu .	Medicago sativa.	Triticum vulgare.	Zea mays.	Andropogon sorghum.	Avena sativa.	Gossypium barbadense.	Beta vulgaris.
$MgSO_4$	$MgSO_4$	$MgSO_4$*	Na_2CO_3	$MgCl_2$	$MgSO_4$*	$MgSO_4$	$MgSO_4$*
$MgCl_2$	$MgCl_2$	$MgCl_2$*	$NaCl$	$MgSO_4$	$MgCl_2$*	$MgCl_2$	$MgCl_2$*
$Na\ CO_3$	Na_2CO_3	$Na\ CO_3$	$NaHCO_3$*	Na_2CO_3	Na_2CO_3	Na_2CO_3*	Na_2CO_3
$NaHCO_3$	Na_2SO_4	$NaHCO_3$	Na_2SO_4*	$NaHCO_3$	$NaHCO_3$	Na_2SO_4*	$NaHCO_3$
Na_2SO_4	$NaCl$	Na_2SO_4	$MgCl_2$	Na_2SO_4	Na_2SOl_4	$NaCl$†	Na_2SO_4
$NaCl$	$NaHCO_3$	$NaCl$	$MgSO_4$	$NaCl$	$NaCl$	$NaHCO_3$†	$NaCl$

* Equally toxic. † Equally toxic.

A study of Table VII shows that, with the single exception of maize, the salts of magnesium are more toxic than those of sodium to all the plants tested.[a] This exception is the more remarkable since three other plants of the same family—wheat, oats, and sorghum—are included in the experiments. In most cases the sulphate of magnesium is more toxic than the chlorid. Sodium carbonate is from twice to four times as toxic to the white lupine, wheat, and maize as is the acid carbonate (bicarbonate), while to the other plants it is only slightly more toxic than the latter. Sodium sulphate, which is generally regarded as a less injurious component of "alkali" soils than sodium chlorid, in pure solutions is more toxic to nearly all the plants tested.

Returning to Table VI in order to compare the powers of resistance of the different plants, we find that maize is on the whole decidedly the most and cotton the least resistant of them all. Wheat stands next to maize among the more tolerant species, while the beet is on the whole the least resistant after cotton. How difficult it is to explain the behavior of plants in relation to saline soils as they occur in nature on the basis of such results as these with solutions of single salts, is shown by the fact that while the sugar beet is one of the plants best adapted to soils of that character, maize is generally regarded as very sensitive.

[a] To the Early Amber variety of sorghum, however, sodium carbonate is nearly or quite as toxic as the magnesium salts.

In tolerance of the two magnesium salts, maize heads the list and cotton comes last. To magnesium sulphate maize is from thirty-six to two hundred times as resistant as the lupine, five hundred times as resistant as the beet, and eight hundred times as resistant as cotton. Even among the four Gramineæ tested there is great difference in tolerance of this salt, maize being one hundred and thirty-three times as resistant as oats. Only less striking are the differences in tolerance of magnesium chlorid, maize, the species that is most resistant to this salt, enduring a concentration of solution two hundred times as great as that which is critical for cotton, the least resistant species.

Less striking results are brought out in the presence of the sodium salts, yet here also marked differences in tolerance occur. Maize endures three times as much sodium carbonate, ten times as much sodium sulphate, seven times as much sodium chlorid, and eight times as much sodium bicarbonate as does cotton.

It is evident from Tables III and IV and from Harter's results with wheat that different plants have widely different degrees of variability inside the limits of the species as regards resistance to salt solutions. Thus the Red Algerian oat is three times as resistant to magnesium sulphate as the Culbertson variety, and of the nine varieties of wheat with which Harter experimented some were three times as tolerant of magnesium chlorid and of sodium carbonate as were others.[a] Of four varieties of *Andropogon sorghum*, one, the Early Amber variety, endured five times as great a concentration of magnesium chlorid as that which was critical for the Dagdi Juar variety. Comparing two closely related species of the same genus, *Gossypium barbadense* and *G. hirsutum*, we find (Table II) that the former is twice as resistant as the latter to sodium carbonate.

RESULTS WITH MIXED SOLUTIONS.

As we have seen, the results of the experiments with solutions containing only a single salt can not be correlated with our knowledge of the relative resistance of the plants used when growing in natural "alkali" soils. Kearney and Cameron[b] pointed out that the clue to this discrepancy was to be found in the fact that in nature we have always to do with a mixture of salts and never with pure solutions. They found that by adding sodium salts to the solutions of magnesium salts the critical concentrations of the latter could be raised considerably and that the neutralizing effect in the case of *Lupinus albus* and *Medicago sativa* became enormous when salts of calcium were added to solutions of the sulphates and chlorids of magnesium and sodium.

[a] See Bul. 79, Bureau of Plant Industry, U. S. Dept. of Agriculture, pp. 25 and 27.
[b] See Report 71, U. S. Dept. of Agriculture, p. 27.

NEUTRALIZING EFFECT OF AN EXCESS OF CALCIUM SULPHATE.

Table VIII gives the critical concentrations of solutions for eight different plant species in the presence of an excess of calcium sulphate. In the case of *Lupinus albus*, *Medicago sativa*, and *Zea mays* these have been worked out with all six of the salts used in the experiments with pure solutions, while for the other species only the limits for magnesium chlorid, sodium carbonate, and sodium chlorid were ascertained.

TABLE VIII.—*Critical concentration for seedlings of various plants in mixed salt solutions (containing an excess of calcium sulphate), expressed in fractions of a normal solution.*

[The figures represent the critical concentrations for the more toxic salts, to which the calcium sulphate was added.]

Salts used (each mixed with an excess of calcium sulphate).	Plants used.*							
	Lupinus albus † (white lupine).	Medicago sativa (alfalfa).	Zea mays (maize).	Triticum vulgare (wheat).	Andropogon sorghum (sorghum).	Avena sativa (oats).	Gossypium barbadense (cotton).	Beta vulgaris (beets).
$MgSO_4$	0.4	0.35±	0.6	....	....	....	....	....
$MgCl_2$	.2	.2 ±	.3	0.225	0.2	0.175	0.25	0.2
Na_2CO_3	.03	.02	.05	.0275	.0225	.1025	.0275	.05
Na_2SO_4	.3	.3	.4 ±	....	....	....	....	....
$NaCl$	.2	.2	.25	.2	.15	.175	.2	.2
$NaHCO_3$	.05	.08	.1 ±	....	....	....	....	....

* The varieties are in all cases the same as those used in obtaining the corresponding limits in pure solutions (see Table VI, page 12).

† Using the fresh lot of seed which gave so much higher limits in pure solutions (see note to table, page 12), Harter repeated the experiments made by Kearney and Cameron with *Lupinus albus* in mixed solutions. In the presence of calcium sulphate, however, Harter's results agree closely with those obtained by Kearney and Cameron (given in Table VIII, column 2) the critical concentrations as determined by Harter being as follows: Magnesium sulphate, 0.35 normal; magnesium chlorid, 0.25 normal; sodium carbonate, 0.0375 normal; sodium sulphate, 0.25 normal; sodium chlorid, 0.175 normal; sodium bicarbonate, 0.058 normal.

In comparing the limits in mixed solutions as stated in the above table with those in pure solutions (Table VI, page 12), we notice that the order of toxicity of the different salts is considerably altered by the addition of calcium sulphate, sodium carbonate being in every case the one that becomes most toxic, while the critical concentrations of the sulphate and chlorid of magnesium become in all cases higher than those of the sodium salts except the sulphate. The neutralizing effect of calcium sulphate is therefore much more marked toward the magnesium than toward the sodium salts.

The presence of calcium sulphate tends very greatly to diminish not only the differences between different species as to their tolerance of the magnesium and sodium salts, but also the differences between the latter in their toxicity to the same species. The first effect is most strikingly illustrated by the limits for maize and white lupine in the presence of magnesium sulphate. The former will endure a concentration of this salt in pure solution from thirty-six to two hundred times as great as is tolerated by the latter. But when an excess of calcium sulphate is added the critical concentration for maize is less than twice that for the white lupine. As an illustration of the tendency to equalization of the toxic effects of the different salts in the presence of calcium sulphate may be mentioned the fact that in pure solutions the sugar beet will endure fifty times as much of sodium chlorid as of magnesium chlorid, while the addition of calcium sulphate makes the critical concentration of both salts the same for this plant.

In some cases the relative resistance of two plants is reversed in the presence of calcium sulphate. Thus, sorghum is more resistant than cotton to pure solutions of magnesium chlorid and of sodium chlorid, but to the mixed solutions cotton is the more resistant. Oats are twice as sensitive as wheat to a pure solution of sodium carbonate, but to sodium carbonate plus calcium sulphate wheat is four times as sensitive as oats.

NEUTRALIZING EFFECT OF SMALLER AMOUNTS OF CALCIUM SULPHATE.

In all of the previously described experiments with mixed solutions, the solutions of magnesium and sodium salts were saturated with the neutralizing agent (calcium sulphate), which was added in excess as a solid.

It was therefore desirable to ascertain whether smaller amounts of calcium sulphate would not neutralize the toxic action of the various salts employed in pure solutions. Two series of experiments were carried out to determine this point, the first with *Lupinus albus*, the second with the Dagdi Juar variety of *Andropogon sorghum*. In the first series sodium chlorid was selected as the salt to be neutralized, while in the second results were obtained with sodium chlorid, sodium carbonate, and magnesium chlorid.

RESULTS WITH LUPINUS ALBUS.

Aqueous solutions of calcium sulphate of definite concentrations were added in equal volume to a solution of sodium chlorid, the concentration of the latter being varied until that was ascertained which represented the critical concentration for the root tips of the lupine seedlings in the presence of the amount of calcium sulphate that was added. A different method was followed in securing the maximum amount of calcium sulphate (3.69 grams per liter), an excess of calcium sulphate being in this case dissolved in various concentrations of the sodium chlorid solution itself,[a] and the latter being then tested until the critical concentration was ascertained. The limits for sodium chlorid in the presence of different amounts of calcium sulphate are stated both in grams per liter and in fractions of a normal solution of sodium chlorid present in the mixed solutions that were found to be critical.

[a] Calcium sulphate is of course much more soluble in a solution of sodium chlorid than in pure water.

TABLE IX.—*Critical concentrations for Lupinus albus in sodium chlorid plus different amounts of calcium sulphate.*

Amount of calcium sulphate present.		Critical concentrations of sodium chlorid.	
Degree of saturation.	Grams per liter in the mixed solution.	Grams per liter in the mixed solution.	Fractions of a normal solution.
Saturated in the NaCl solution	3.69	11.7	0.2
One-half saturated in H_2O	*1.062	12.3	.21
One-fourth saturated in H_2O	.531	12.5	.21
One-eighth saturated in H_2O	.265	10	.17
One-sixteenth saturated in H_2O	.132	7.5	.13
None	None.	1.17	.02

*Cameron (The solubility of gypsum in aqueous solutions of sodium chlorid, Journal Phys. Chem., 5:556, 1901) has shown that calcium sulphate dissolves in water at a temperature of 26° C. at the rate of about 1 part per 470 of water; hence at the rate of about 2.125 grams per liter. Marignac and Goldammer obtained similar results.

We see from these results that the maximum neutralizing effect of calcium sulphate upon sodium chlorid in raising the critical concentration of the latter for white lupine seedlings is reached when the mixed solution contains 0.5 gram of the calcium salt, and that the endurable concentration of sodium chlorid can be raised no further although the amount of calcium sulphate present be increased more than seven times. At concentrations below 0.5 gram per liter the effect of the calcium salt gradually diminishes. It would be interesting to ascertain the minimum amount of calcium sulphate that can perceptibly diminish the toxic effect of sodium chlorid.

RESULTS WITH ANDROPOGON SORGHUM.

In this series of experiments a saturated solution of calcium sulphate in water was prepared and was then diluted with distilled water to the desired concentrations. Normal solutions of sodium chlorid, sodium carbonate, and magnesium chlorid were obtained and then brought to the concentration that is critical in the presence of an excess of calcium sulphate by diluting with the different concentrations of the calcium sulphate solution that were used.[a] The object of this series of experiments was to ascertain the minimum amount of calcium sulphate which would have as complete neutralizing effect upon the more toxic salts as could be obtained by saturation with the calcium salt.

[a] Since the normal solutions contained no calcium sulphate it was necessary to correct for this in determining the amounts of calcium sulphate present in the total volume of the mixed solutions.

TABLE X.—*Minimum amounts of calcium sulphate giving the maximum neutralizing effect upon the toxicity of other salts to Andropogon sorghum.*

Salts neutralized.	Critical concentration when saturated with calcium sulphate.		Minimum amount of calcium sulphate giving neutralizing effect equivalent to that of saturation.	
	Fractions of a normal solution.	Grams per liter.	Fractions of saturation in the total volume of water in the mixed solution.	Grams per liter in the mixed solution.
Sodium chlorid	0.15	8.8	0.053	0.112
Sodium carbonate	.0225	1.2	.183	.389
Magnesium chlorid	.2	9.5	.3	.637

Comparing the results as to sodium chlorid given in Table X with those given in Table IX, we see that, while the concentration of that salt which is critical for *Lupinus albus* can be raised to 0.2 normal by the addition of calcium sulphate, for *Andropogon sorghum* the limit can be raised to only 0.15 normal. On the other hand, the minimum amount of calcium sulphate required to produce the maximum neutralizing effect is only about one-fifth as great for the latter plant as for the former. Table X also shows that the maximum neutralizing effect is obtained by widely different amounts of calcium sulphate in the case of each of the three more toxic salts, and that the more toxic the salt in pure solution the greater is the amount of calcium sulphate required to produce the maximum possible neutralizing effect.

If we compare the limits of this variety of *Andropogon sorghum* in pure solutions, as stated in column 5 of Table III (p. 10), with those in mixed solutions, as given in Table X, we observe that the critical concentration of magnesium chlorid can be raised one hundred and sixty times by the addition of calcium sulphate, while that of sodium carbonate can be raised only three and six-tenths times. Yet to obtain the former result less than twice as much calcium sulphate is required as to obtain the latter.

To neutralize sodium carbonate as completely as possible, three and one-half times as much calcium sulphate is required as in the case of sodium chlorid, although the fraction of a normal solution representing the critical concentration of the mixed solution is only one-seventh as great for the former salt as for the latter. Six times as much calcium sulphate is needed to produce the greatest possible neutralizing effect upon magnesium chlorid as upon sodium chlorid, yet the critical concentration of the former in the mixed solution is only slightly greater than that of the latter.

That there is no close quantitative relation between the amount of the more toxic salt present in the mixed solution and that of calcium sulphate necessary to neutralize it is evident from the fact that, in weight of salt per liter of solution, the minimum amount of calcium sulphate necessary to effect the maximum possible neutralization, as compared with the amount of the more toxic salt present in the mixed solution, is about one-third in the case of sodium carbonate, one-fifteenth in that of magnesium chlorid, and one-eightieth in that of sodium chlorid. This is a strong indication that the neutralizing effect is a physiological one, and that it can probably be satisfactorily explained only when the composition and properties of living protoplasm are better understood.

Prof. O. Loew and his students, in numerous papers dealing with the "lime-magnesia ratio," have thrown much light upon the effect of calcium salts in neutralizing the poisonous action of salts of magnesium. The physiology of the decrease in toxicity of salts of sodium and magnesium brought about by the presence of a second salt, especially a salt of calcium, in the solution, was discussed by Kearney and Cameron[a] in connection with Loeb's striking results with marine animals. Osterhout[b] has recently investigated this subject from the point of view of Loeb's conception of a "physiologically balanced solution" and has shown that marine plants as well as marine animals are very sensitive to pure salt solutions, but thrive in solutions containing a mixture of salts, even when each component is present in an amount that is toxic in pure solution. A mixture of the more important salts present in sea water, each at about the concentration at which it occurs in the sea, was found to be the best medium for the growth of marine algæ.

> The plants die much sooner in a pure sodium chlorid solution (isotonic with sea water) than in distilled water. The poisonous effect of the NaCl largely disappears if we add a little $CaCl_2$. * * * In this mixture the plants live nearly as long as in distilled water. Addition of KCl to this mixture enables them to live longer than in distilled water. Further addition of $MgCl_2$ and $MgSO_4$ enables them to live practically as long as in sea water.[c]

SUMMARY.

(1) Different varieties of the same species, e. g., of wheat (*Triticum vulgare*), sorghum (*Andropogon sorghum*), and oats (*Avena sativa*), differ considerably in their powers of resistance to the action of magnesium and sodium salts in pure solutions.

(2) Closely related species of the same genus, e. g., Egyptian and Upland cottons (*Gossypium barbadense* and *G. hirsutum*), show similar differences.

(3) Great differences exist between different plant species, even when belonging to the same family, in tolerance of pure salt solutions,

[a] Report No. 71, U. S. Dept. of Agriculture, 1902, pp. 40 to 47.

[b] Jour. Biol. Chem., 1:363 to 369, 1906, and Bot. Gaz., 42:127 to 134, 1906.

[c] Osterhout in Bot. Gaz., 42: 130 (1906).

not only as regards the absolute toxicity of each salt but also as regards the relative order of toxicity of the salts. Of the eight species used in these experiments maize (*Zea mays*) is, on the whole, the most resistant to pure solutions, and cotton (Gossypium) the least.

(4) Seedlings grown from fresh seed are much more resistant than those developed from older seed.

(5) The presence of calcium sulphate in excess greatly diminishes the toxicity of the magnesium and sodium salts to all the plants tested, the neutralizing effect being greatest in the case of the sulphate of magnesium and least in that of sodium carbonate.

(6) The addition of calcium sulphate tends to equalize the toxicity of the different magnesium and sodium salts.

(7) As a rule, the more sensitive the species to the pure solution the greater is the counteracting effect of the calcium salt; hence, the presence of the latter tends to diminish the differences in resistance shown by different plant species in the presence of pure solutions.

(8) Amounts of calcium sulphate smaller than that necessary to saturate the mixed solution also show a marked neutralizing effect upon the more toxic salt, but the minimum amount of calcium sulphate capable of producing such effect remains to be determined.

(9) For the white lupine the presence of 0.5 gram of calcium sulphate is as effective as seven times that amount in neutralizing sodium chlorid, while for sorghum 0.1 gram is as effective as twenty times that amount.

(10) To secure the most effective possible neutralization of sodium chlorid five times as much calcium sulphate is required in the case of the white lupine as in that of sorghum, although the limits for these two plants are approximately the same both in pure sodium chlorid and in sodium chlorid plus an excess of calcium sulphate.

(11) While the comparative resistance of the different plants to pure solutions of the single salts can in no way be correlated with that of the same species to the different combinations of "alkali" salts occurring in western soils, their behavior in mixed solutions shows a much closer approach to that observed under natural conditions.

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