Bulletin No. 102 March 31, 1925

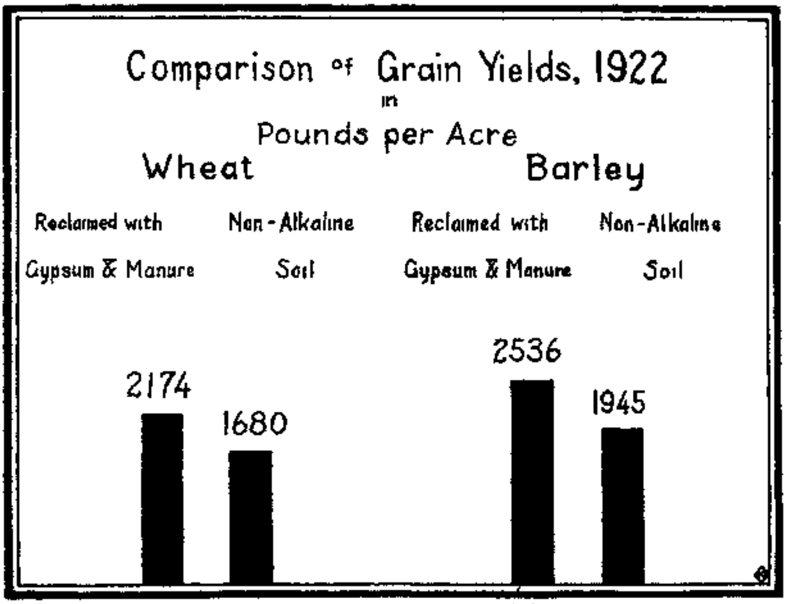
University of Arizona

College of Agriculture

Agricultural Experiment Station

TREATMENT OF BLACK ALKALI WITH GYPSUM

By C. N. Catlin and A. E. Vinson



Comparison of grain yields, 1922

PUBLISHED BY
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ILLUSTRATIONS

TABLES

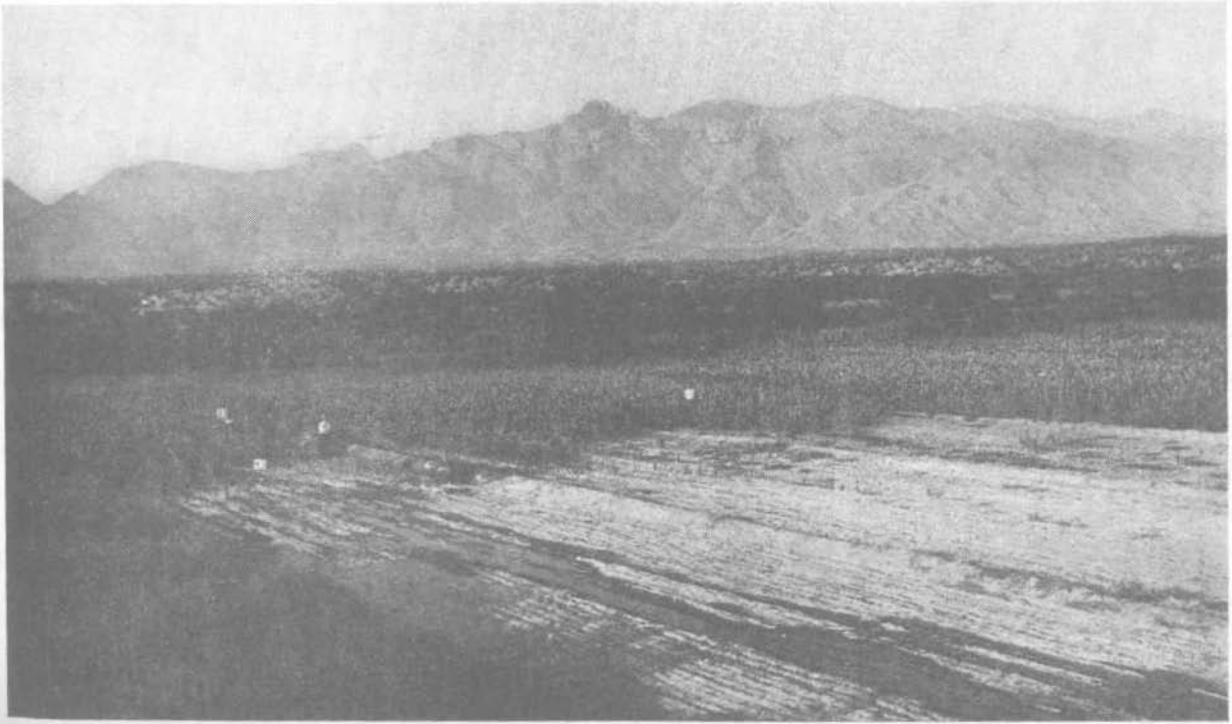

Fig. 1.—Feterita on north half of black alkali plots before treatment, November, 1915.

TREATMENT OF BLACK ALKALI WITH GYPSUM

By C. N. Catlin and A. E. Vinson

INTRODUCTION

Black alkali is recognized as the most troublesome form of alkali occurring in the Southwest. It is poisonous to cultivated crops in relatively weak concentrations and has a most deleterious effect on the mechanical structure of the soil. The term includes both carbonate of soda and bicarbonate of soda, known also as washing soda and baking soda. While the carbonate is the more difficult to handle and destructive in its action, we do not believe it worth while to make more than temporary distinction between these two forms of sodium carbonate in this publication, One probably shifts rapidly into the other as field conditions change. The presence of free carbon dioxide from any source will change carbonate to bicarbonate and the loss of carbon dioxide by heat or other agencies will reverse the process. In this bulletin, therefore, carbonate and bicarbonate are treated collectively as carbonate.

ORIGIN OF BLACK ALKALI

Several ways are recognized in which black alkali may originate. It may be formed by the action of sodium salts on calcium carbonate.[1]

The resulting soluble calcium compounds are then leached away, leaving black alkali, which in turn may be transported and appear elsewhere. Black alkali may also originate in the weathering of feldspathic and basic rocks. This is the probable origin of the sodium carbonate at the University Farm. The ground water there is faintly black alkaline, as are the streams from the Santa Catalina Mountains that recharge the underground reservoir. In certain lacustrine soils black alkali may have

[1]Breazeale, Jour Agr Research, Vol 10, No 2

been absorbed and retained from the alkaline water in which these soils were deposited.

Black alkali[1] is also formed when saline soils are leached with relatively pure water. The formation of sodium carbonate under these conditions appears to take place in the following way: When solutions of sodium salts are brought into contact with soil colloids, an exchange of bases takes place, the sodium releasing a corresponding amount of calcium, magnesium, and potassium, and forming sodium-silicate complexes, which for convenience may be spoken of as sodium "absorbates". So long as the salinity of the water used for leaching remains above a certain concentration, no alkali is formed and percolation goes on readily, When purer water is substituted and the salinity of the system reduced, hydrolysis of the sodium "absorbate" takes place. This is accompanied by carbonation and the formation of black alkali with deflocculation of the soil and consequent slowing down of percolation until the soil may become nearly impervious. Similar results may follow the use of irrigating water that carries too high a ratio of sodium to calcium and magnesium salts.[2]

RESISTANCE OF BLACK ALKALI TO LEACHING

Soils that are merely salty may be reclaimed under some conditions by direct leaching, but not so when sodium carbonate is present. Black alkali, whether original or resulting from the hydrolysis and carbonation of sodium "absorbates", resists leaching persistently until the soil is treated chemically to neutralize the sodium carbonate[3], at least in part, and bring about flocculation of the clay. Those who have investigated the reclamation of black alkali soils are agreed on this point. Various neutralizers of black alkali have been used, beginning first with gypsum which was introduced by Shinn[4] and Hilgard and since has been used by Headden and many others. More recently nitric acid[5], sulphuric acid[6], sulphur[7], and finally alum[8] have been advocated for this purpose. In pot cultures and laboratory percolation tests we have used quite successfully

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[1]Gedroiz, 1912, Unpub. transl. from the Russian by Dr. S. A. Waksman, 1923. Cummins and Kelley, Tech. Paper No. 3, March 1923, Univ. of Calif., Berkeley. This paper gives an extensive bibliography.

[2]Scofield and Headley, Jour. Agr. Research, Vol. 21, No. 4.

[3]Hibbard, Soil Sci,, Vol. 13, No, 2.

[4]Cal. Sta. Rep., 1893-94, p. 145.

[5]Symmonds Agr. Gaz. N. S. Wales, 21, No. 3, p. 257, through Harris, Soil Alkali, John Wiley and Sons, 1920.

[6]C. B. Lipman, Cal. Pub. Agr. Sci. 1 (1915) p. 275.

[7]J. G. Lipman, Soil Sci., Vol. 2, p. 205. P. L. Hibbard, ibid, Vol. 11, p. 385. J. S. Joffee and H. C. McLean, Sci., Vol. LVIII, July 20, 1923, p. 53.

[8]Scofield in his experiments at the Newland's Exper. Farm, Fallon, Nev.

other chemicals, such as manganese and ferrous sulphates and even such organic acids ab tartaric and citric. Each of these materials brings about flocculation of the soil and offsets the toxicity of the black alkali as measured by crop growth.

The correction of black alkali may be brought about in some cases by calcium salts dissolved in the irrigating water. Gypsum waters are not uncommon, and waters containing 30 parts per 100,000 or more of calcium nitrate are used in Salt River Valley. The action on alkaline soils of calcium bicarbonate carried by the irrigating water requires special consideration. Does calcium as bicarbonate tend to counteract sodium when applied to calcareous soils? Unpublished results obtained recently by J. F. Breazeale in this laboratory show that calcium bicarbonate solutions as a rule percolate more readily through the University Farm calcareoub black alkali soil than do gypsum solutions of like calcium concentration. The effect appears to depend solely on the bicarbonate, and it is probable that all the calcium is deposited as carbonate near the surface of the soil. The percolate with the gypsum water shows calcium, whereas that with the calcium bicarbonate water docs not show calcium. While the soils treated with bicarbonate remain open and percolate well so long as the calcium bicarbonate solution is used, the effect appears to be temporary, and the soil becomes clogged again when purer water is substituted, which is not the case with gypsum. According to these observations sulphuric acid should prove doubly effective in improving percolation through calcareous black alkali soils. The combined benefits of the gypsum formed from the acid and of the carbon dioxide released from the calcium carbonate would be obtained. This is in harmony with laboratory and field results with sulphuric acid on calcareous soils as observed by us.

We have frequently observed the futility of trying to leach black alkali in our laboratory experiments which will be described later, and similar experiences have been noted by others.[1] It is freely admitted that part at least of the residual black alkali in these cases may be due to the hydrolysis of sodium "absorbates" just as is the case when non-alkaline saline soils are leached. In 1919 an instructive experiment[2] in the reclamation of black alkali land was made inadvertently by Messrs. Goodin and Eder in an attempt to grow rice on a tract adjacent to the Tempe Date Orchard on which the water table had been lowered recently to about 5½ feet. Unfortunately our cooperation in the experiment was not invited until after the first leaching. It was then too late to make a careful study of the original condition of the soil, and we were forced

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[1]Hibbard, loc. cit.

[2]Ariz Sta. 30th Ann. Rep., p. 406.

to get such information by indirect and more or less uncertain means. Nevertheless, the tenacity with which black alkali persisted after prolonged leaching could not be doubted, especially after the second leaching, which was made with our cooperation. The Goodin-Eder tract once had been among the best in the Salt River Valley; but as the water table came up, the land had been abandoned to Bermuda grass, which in turn had given way to saltbush. The Tempe Drainage Ditch had improved matters somewhat by lowering the water table at most to 5½ feet. This, however, is not sufficient in soil of that texture for effective leaching and permanent reclamation. The results given in Table I show conclusively that the chlorides and salts other than black alkali had been removed successfully, but that the black alkali persisted with relatively little change after weeks of continued leaching. The lands represented by samples 7,359, 7,360, and 7,361 had been heavily irrigated and finally submerged for 30 days in an attempt to grow rice. Several days elapsed after the water was taken off and before we were asked to analyze the samples; consequently, we feared that more or less alkali had come up during the interval. The owners, being anxious to reclaim the tract, again put the lands represented by samples 7,360 and 7,361 under water for another 21 days. The soils now took water more readily than they did the first time, and between 4 and 5 feet were allowed to percolate. Immediately at the close of the second treatment, samples 7,383 and 7,384 were taken and analyzed with the results recorded. Samples 7,362, 7,363, 7,364, and 7,365 probably give a fair idea of alkali conditions on the tract before the experiment was started. Samples 7,366, 7,367, and 7,368 from neighboring ranches were thought to be similar to the land under investigation before leaching. Sample 7,366 represented land that had been fallow for 6 or 7 years with the exception of one or two unsuccessful attempts to grow milo. It had been flooded during the winter of 1918, then planted to cotton in April, 1919, and grew a fair stand without irrigation during the season. Sample 7,367 was from the same ranch and had been covered with Bermuda grass that had been killed out by alkali. A new planting of Bermuda grass was made in 1917 and irrigated every 10 or 12 days, giving a fair stand by fall. In 1918 the Bermuda sod was broken up and the land planted to Pima-Egyptian cotton, which was irrigated only after planting. It yielded ½ bale per acre. The land was again irrigated heavily during the fall and winter of 1918 and planted to cotton in 1919. It yielded three-quarters of a bale or more to the acre. The land represented by 7,368 has been cropped continuously in past years and in 1918 yielded a bale of cotton per acre. It was irrigated after the last picking and heavily irrigated during winter, but never during the crop season.

TABLE I.—LEACHING OF BLACK ALKALI ON THE GOODIN-EDER TRACT WITHOUT CHEMICAL TREATMENT.

Lab. No.	Description	Depth of sample	Total soluble salts	Chlorides as NaCl	Black Alkali as Na_2CO_3
		Inches	Percentage	Percentage	Percentage
7,359	Irrigated four times, one week apart, submerged periods of 10 days each in July and August.	0-4	.408	.044	216
		4-12	.404	.080	229
		12-24	.408	.174	167
7,360	Flooded six times in June and early July, then submerged 30 days.	0-4	.560	104	288
		4-12	.513	.154	237
		12-24	.320	.126	.161
7,361	Same treatment as 7,360.	0-4	464	.072	233
		4-12	.540	.15	220
		12-24	.440	.18	161
7,362	Elevated land flooded four times during season.	0-4	3.856	2.52	254
		4-12	2.008	1.26	110
		12-24	496	.26	161
7,363	High land, flooded but never kept submerged; representative of original.	0-4	2 16	1 60	038
		4-12	320	.072	.135
		12-24	168	.048	.085
7,364	Irrigated twice in season of 1919.	0-4	1 36	.58	.271
		4-12	752	.32	186
		12-24	332	.096	153
7,365	Not irrigated for 2 years.	0-4	1 52	.88	322
		4-12	.369	.12	191
		12-24	.256	.06	169
7,383	Same as 7,360, submerged.	0.12	.32	.020	135
7,384	Same as 7,361, resubmerged	0-12	.296	.012	178
7,366	Frankenburg ranch ¼ mile distant; similar untreated land.	0-4	.536	164	220
		4-12	.736	288	178
		12-24	.526	220	119
7,367	Same.	0-4	1.3	.74	102
		4-12	.840	44	135
		12-24	.520	24	161
7,368	S. E ¼ of same section.	0-4	.36	.060	051
		4-12	.52	.236	169
		12-24	512	204	186

BLACK ALKALI CONDITIONS AT UNIVERSITY FARM

THE ORIGINAL LAND

The extreme importance to Arizona of the black alkali problem was realized soon after the organization of the Experiment Station, and Timely Hint for Farmers No. 11, May, 1900, discussed this subject It was not, however, until after the purchase of the University Farm in 1909 that land became available for field experiments in the reclamation of black alkali. Originally the farm was in heavy mesquite which tolerates rather strong alkali when once established. After the mesquite had been cleared, the more alkaline parts of the farm not under cultivation became covered with a luxuriant growth of black alkali weed (*Wislizenia refracta*), interspersed with alkali purslane (*Triantnema portulacastrum*), burro weed (*Dondia moquini*), and a small annual aster, (*Machaeranthera parviflora*). Certain small areas of the farm, among the first to be cultivated, that were more alkaline and did not support a good stand of alfalfa were treated with a few carloads of gypsum from Douglas, Arizona. Although the treatment gave good results, it was realized that the expense would not be justifiable for large areas; consequently, further treatment was abandoned until an easily accessible deposit of gypsum in the foothills about 4 miles from the farm was brought to our attention. We then began a systematic study of the reclamation of a small area in the worst of the alkali on land that had been leveled in 1913 and planted to barley in an attempt to increase the productive area on the farm. This part of the farm lies in an old channel of the river with somewhat higher land between it and the present river bed. While, normally, the water table is 14 to 16 feet below the surface at the farm well, in periods of flood standing water has been found with the soil auger at 4 or 5 feet on the experimental area. An unmistakable rise of alkali to the surface has always accompanied these periods of high water table.

PHYSICAL PROPERTIES OF THE UNIVERSITY FARM SOIL

Physical Constants:—The soil of that part of the University Farm on which these experiments were conducted is a very fine sand or fine sandy loam. It is always loose and easily worked, and the more alkaline areas are soft and feathery on the surface, as is common with strongly alkaline soils. Despite the sandy character of the soil, the black alkali present soon causes it to clog under water and become almost impermeable. During a heavy shower the more strongly black alkaline areas may be distinguished by their gloss as compared with the dead finish on the surrounding, less alkaline areas. The mechanical analysis of the soil gives the following result:

TABLE II.—MECHANICAL ANALYSIS OF UNIVERSITY FARM SOIL, BLACK ALKALI PHASE,

Fine gravel	2 to 1 mm.	.36 percent
Coarse sand	1 to .5 mm.	1.66 percent
Medium sand	.5 to .25 mm.	3.50 percent
Fine sand	.25 to .10 mm.	21.90 percent
Very fine sand	.10 to .05 mm.	45.40 percent
Silt	.05 to ,005 mm.	11.34 percent
Clay	below .005 mm.	15.80 percent
		99.96 percent
Loss on ignition		2 76 percent

The moisture equivalent of this soil is 8.0 and its swelling coefficient[1] when the dry soil is wetted is 67.5.

RATE OF PERCOLATION BEFORE AND AFTER TREATMENT

The rate of percolation of water through a very black alkali phase of the University Farm soil before and after treatment with gypsum has been thoroughly studied. The saving of plant foods by gypsum treatment before leaching has also been studied and will be discussed under the chemical properties of this soil. The first percolation tests were made in 10-inch flower-pots with 10 kilograms of the soil. It has been noticed previously that the soil clogged after being under water a short time and percolation became very slow, finally stopping entirely. Four pots were prepared: one without gypsum, and the others with one-half, just enough, and twice as much gypsum, respectively, as would be required to react with the sodium carbonate found by analysis [2] in the soil. The gypsum was mixed with the dry soil and the mixture kept wet 5 and 7 days, respectively, before the percolation test was made. One liter of water was poured over the soil and the percolate measured for 6 hours in the 5-day series, and for 5 hours in the 7-day beries. From these the amount of percolation in 24 hours was calculated. The results of this experiment are reported in Table III.

The very remarkable changes in the rate of percolation with varying amounts of gypsum seemed to warrant further study. It appeared that if gypsum were added to flocculate the soil and promote the percolation of water, triple the effect would be obtained by adding the second half-equivalent. Consequently, it would pay best to use the full amount in

[1]Vinson and Catlin, Jour. Amer. Soc. Agron. Vol. 14, p 302

[2]Headley, Curtis, and Scofield, Jour. Agr Research, Vol. 6, p. 8S7, present experimental evidence to show that the sodium carbonate recoverable by analysis is more nearly related to plant behavior than is the amount added to a soil, and that, when sodium carbonate is added, only a part can be found by analysis. If the added portion be small, none of it may be recoverable. The writers in 1913 (Ariz. Exp. Sta. 24th Ann. Rep., p. 274, quoted by F. S. Harris in Soil Alkali, p. 85) showed further that the amount of black alkali recoverable from a soil depended especially on the method of solution, and that there was no correlation between the results obtained by the several methods in use by different chemists when applied to soils of different texture. The method used by us consists in digesting 50 grams of the dry soil passing a 1.5 mm. sieve with about 800 cc. of water in a 1,000 cc. graduated flask for 10 hours on the water bath. The flask is then filled to the mark and allowed to stand over night, again filled to the mark and filtered through a type F. Chamberlain filter. The soil solution is then analyzed as an irrigating water according to Official Methods A. O. A. C., page 40, with modifications as to strength and quantity of solutions. According to investigation in this laboratory the maximum extraction of black alkali with the heavier types of soil is not attained in less than 10 hours* hot digestion and the dilution specified. It is essential, therefore, in giving the black alkali content of a soil to state the method of solution.

field practice. Our experiments with this soil in pot cultures, so blended AS to contain the toxic limit[1] of 0.2 precent sodium carbonate, by analysis show that actual crop production does not parallel the effect on percolation, but that a considerable residue of unneutralized black alkali is without injury to the plants used when compared with those to which an excess of gypsum has been added.

TABLE III.—RATE OF PERCOLATION THROUGH BLACK ALKALI SOIL AFTER DIFFERENT TREATMENTS WITH GYPSUM.

Treatment	Amount percolated in 24 hours	
	Wet 5 days	Wtt 7 days
	cc	cc
No gypsum	400	288
One-half equivalent	880	696
Exact equivalent	2,560	2,112
Double equivalent	3,680	4,320

The use of pots in studying the rate of percolation proved quite unsatisfactory because concordant results could not be secured in duplicate experiments. Glass percolators, similar to those often used for class work in soil physics, gave equally unreliable results. The most satisfactory apparatus, according to our experience, is the brass-cylinder percolator, also used in soil laboratories. Even with these, frequently a difference of several hours is observed in the time required for the first drop to come through. The percolation tests were repeated with the brass-cylinder percolators and many chemicals were studied as to their effect on the rate of percolation. The curves in figure 2 trace the effect of gypsum on the rate of percolation through the University Farm black alkali soil. The values on the abscissa show the time elapsed since water was applied, while those on the ordinate show the amount of percolation. Although these results are more accurate, they confirm in a general way the conclusion drawn from the flower-pot experiments.

CHEMICAL PROPERTIES OF THE UNIVERSITY FARM SOIL

No complete chemical analyses of the University Farm soil have been made. The writers believe that no useful information bearing on

[1]In a separate study, the details if which arc given on p. 310 of this bulletin, it was found that 0,25 percent sodium carbonate prevented all growth of barley and permitted only a scant growth of Sonora wheat; 0.20 percent sodium carbonate permitted a scant growth of both grains and therefore was chosen as the working toxic limit for this type of soil at which the effect of different treatments and other changes in concomitant conditions may be studied.

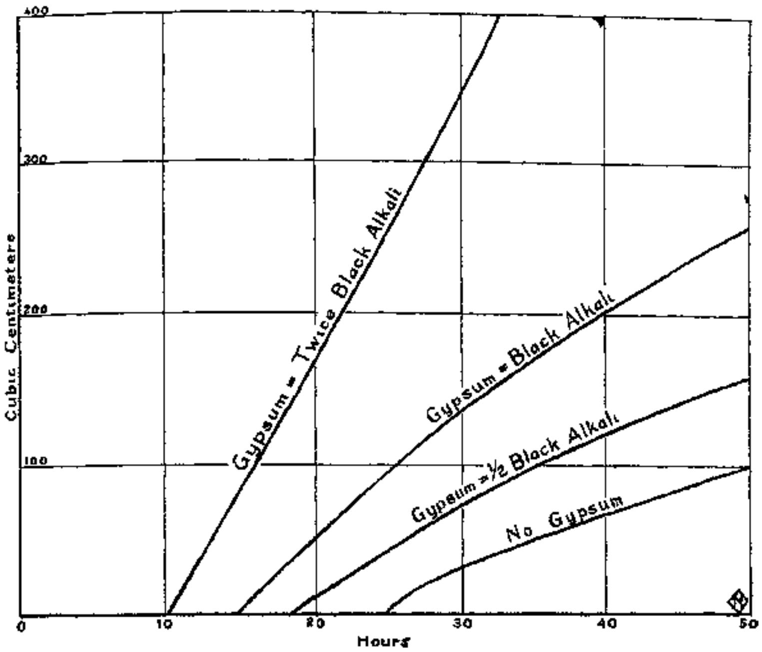

Fig 2.—The effect of gypsum treatment on the rate of percolation through the University Farm black alkali soil

the alkali problem could be derived from such an analysis at this time. On the other hand several hundred samples have been analyzed for alkali, together with a few special samples for nitrogen and total carbonates. The total carbon dioxide calculated as calcium carbonate as it was found November 17, 1922, in three bore holes will be found in Table XIV.

Sampling Alkaline Soils:—In general we have found that, in the study of alkali, samples from a single bore hole give more information than could be had from large composite samples, although in some cases we have had recourse to composite samples. Samples from a hole in a small area showing a fair growth of crop sometimes contain more alkali than adjacent soil on which the same crop has failed to make a stand. Admittedly, other conditions than alkali content are involved. On one occasion we sampled a square yard to the depth of 2 feet by removing the soil in 2-inch layers which were carefully sampled and analyzed.[1] The result showed a change from black alkali into gypsum or its equivalent and back into black alkali within the 2 feet. Samples representing the same area by 1-foot sections would not have revealed the presence of the

[1]Ariz. Sta. 30th Ann. Rep., p. 405.

non-black alkaline stratum, but would have shown all to be black alkaline. In securing soil for pot cultures we have analyzed samples from different parts of the field to find the desired alkali content. A ton or more of soil from the same spot has then been sampled after repeated mixing and sifting, and in some instances has differed so greatly in composition from the field sample that it could not be used for the purposes for which it was selected. Samples taken in the same spot a week apart often have been found to differ greatly in alkali content. These examples are given to illustrate the extreme difficulty of determining definitely the concentration of alkali under field conditions. Soluble salts in alkaline soil appear to be shifting continuously so that their concentration may be likened, at least remotely, to the coloring in marble with the mottling imagined to be shifting slowly about. Many of the apparent discrepancies in analyses relating to this investigation may be explained on this hypothesis.

KIND AND AMOUNT OF ALKALI AT UNIVERSITY FARM

Samples of soil from the University Farm have given as high as 0.7 percent sodium carbonate and over 2 percent of soluble salts. The general alkali situation, however, on that part of the farm used for these experiments is shown more representatively in Tables IV and V. Samples Nos. 5,993, 5,994, 5,995, 5,996, and 5,997 in Table IV represent borings made in 1915 to determine the amount of gypsum that would be needed to neutralize the black alkali in these soils. A light application of gypsum, much less than indicated as needed by the analyses, was made at that time without much apparent effect. Nos. 6,197 to 6,200 in the same table represent samples taken from an adjoining alfalfa field that never had received gypsum. No. 6,197 was from bare ground; No. 6,198 from ground with alfalfa barely growing; No. 6,199, alfalfa showing effects of the alkali; and No. 6,200, good crop of alfalfa.

TABLE IV.—ALKALI IN UNIVERSITY FARM SOIL, 1915, AFTERWARD TREATED WITH GYPSUM

No.	Soluble solids	Chlorides as sodium chloride	Calcium sulphate	Black alkali as sodium carbonate
	Percentage	Percentage	Percentage	Percentage
5,993	.41	.012		.204
5,994	.23	.012		.102
5,995	.62	.040		.254
5,996	.24	.008		.034
5,997	.97	.088		.297
6,197	.82	.024		.331
6,198	.42	.012		.119
6,199	.27	.012		.051
6,200	.29	.012		.038

TABLE V.—ALKALI IN UNIVERSITY FARM SOIL, 1918, TO DEPTH OF 6 FEET. COMPOSITE SAMPLES

Depth	Soluble solids	Chlorides as sodium chloride	Calcium sulphate	Black alkali as sodium carbonate
	Percentage	Percentage	Percentage	Percentage
1st foot	.28	016		.051
2nd foot	.40	.008		.085
3rd foot	.59	.004		.220
4th foot	43	016		.169
5th foot	.58	.036		.204
6th foot	53	024		.119
1st foot	.54	052		.054
2nd foot	32	020		.034
3rd foot	54	.036		.169
4th foot	.15	.008		.034
5th foot	.44	.036		.169
6th foot	.85	.132		.322

In 1918 a large number of borings were made and samples analyzed to determine more exactly the amount of gypsum needed to treat this same tract effectively. Composite samples, foot by foot, to the depth of 6 feet were analyzed and results are given in Table V.

The analyses show the sodium chloride content of the University Farm soils to be very low. This is fortunate for the study of black alkali, since salinity is thus eliminated as a complicating factor. The difference between black alkali and soluble solids is made up chiefly of sodium sulphate and organic matter. Sodium sulphate is the least harmful form of alkali, and in this soil we have never regarded it as an important factor in inhibiting crop growth. It is also readily leached from the soil. Total carbonates estimated as calcium carbonate have been determined in a special set of samples taken at the close of the 1922 experiments and are reported in Table XIV in connection with samples showing the residual alkali in 1922. The black alkali as shown in Table V is stronger in the subsoil than at the surface, prohibitive amounts being reached at a depth of 3 feet. It must be remembered, however, that the smaller amounts in the surface soil may deflocculate the clay so completely as to disturb seriously the water relation of the soil by rendering it hard and impervious,

SAVING PLANT FOODS BY GYPSUM TREATMENT

The effects of leaching on the soluble plant foods in the soil before and after treatment with gypsum were investigated by us and are significant. For this experiment a very strongly black alkali soil containing 0.7 percent sodium carbonate and over 2 percent of soluble salts was selected. Ten kilograms of the soil were placed in each of four 10-inch paraffined flower-pots. After treatment with appropriate amounts of gypsum corresponding to those used in the percolation test (See Table III), except that two and one-half times the black alkali equivalent was mixed with the last pot, 5,700 cc. of water was added. The volumes of the percolates were recorded and the total amounts of soluble solids, nitrogen, phosphoric acid, potash, and colloidal organic matter (precipitated by acidifying the percolate) were determined. The results are recorded in Table VI.

This table teaches several valuable lessons regarding the use of gypsum before attempting the reclamation of black alkali land by leaching. If we assume an acre-foot of soil to weigh 4,000,000 pounds, which ib too low rather than too high for a sandy soil, we find that in removing about 400 tons of soluble salts we have sacrificed 70 pounds of nitrogen, 214 pounds of phosphoric acid, 1,350 pounds of potash, and about 700 pounds of humus material. Even a relatively light application of gypsum effects a considerable saving of this soluble plant food and much larger savings

TABLE VI.—LOSS OF PLANT FOODS BY LEACHING BLACK ALKALI SOIL BEFORE AND AFTER GYPSUM TREATMENT.

Gypsum used	Total percolate	Soluble solids	Nitrogen	Phosphoric acid, P_2O_5	Potash K_2O	Colloidal organic
Grams	cc	Grams	Grams	Grams	Grams	Grams
None	2,115*	197.75	.175	535	3.388	1 768
70.4	2,270	18991	103	.394	2.284	0 445
140.8	2,195	189 64	.082	.170	2,400	0 237
352.0	2,046	209 84	.055	.030	3 067	0 105

*Percolation stopped

are effected by a more liberal use of gypsum. Only when large amounts of gypsum are used does there appear to be no appreciable saving of potash, It is a well accepted theory that gypsum renders potash soluble, but here in the presence of large amounts, at least no more potash was lost than in the absence of gypsum. The saving of a large part of the several kinds of plant food is probably dependent on the precipitation of the colloidal organic matter, but we did not try to get any data on this point. The commercial value of the plant foods saved would go far toward paying the expense of the treatment, especially where gypsum may be had for little more than the expense of handling. We do not believe that this fact has been sufficiently recognized in discussing the use of gypsum as a neutralizing and flocculating agent in reclaiming black alkali soils. Undoubtedly the same may be said of sulphuric acid, aluminum sulphate, iron salts, and other chemicals that can be used for this purpose, since they also throw down the colloidal organic matter of the soil.

After the soils had been leached, they were dried, sampled, and again analyzed for residual alkali. Table VII gives the alkali content of these soils and of the original unleached soil. The table again brings out the fact very strikingly that chlorides and saline salts are easily removed by leaching, but that black alkali is retained tenaciously until neutralized.

TOLERANCE OF CROPS FOR ALKALI IN UNIVERSITY FARM SOIL

UNDER FIELD CONDITIONS

Among the first observations made on the black alkali conditions at the University Farm were attempts to establish the limit of tolerance for alkali by the crops grown. Here on soil of very uniform texture were all gradations of crop growth from a perfect stand of healthy, vigorous plants to bare, alkali-covered ground. In Table IV, Nos. 6,197 to 6,200 give data referring to alkali tolerance by alfalfa which is also of interest in this connection. The samples used in the study of alkali tolerance were

TABLE VII—ALKALI CONTENT OF ORIGINAL SOIL AND OF THE SAME LEACHED BEFORE AND AFTER GYPSUM TREATMENT.

Gypsum used	Soluble solids	Chlorides as sodium chloride	Calcium sulphate	Black alkali as sodium carbonate
Grams	Percentage	Percentage	Percentage	Percentage
Original	215	.0472		.704
None	.68	.03		.326
70 4	.71	.03		.220
140.8	.89	.028		.076
352 0	1.57	.028	.555	

taken with the boil auger by boring at the root of a plant representative of the group. The many discrepancies that were encountered in this investigation lead us to a study of the concomitant conditions that influence the toxicity of black alkali to crops under field conditions.

The results of these field observations are recorded in Table VIII. Feterita grew on the experiment plot in 1915 and the soil samples were taken in November of that year (See Fig. 5). Barley followed the feterita and the soil was sampled May, 1916 (See Fig, 6). A study of the results shows the almost utter hoplessness of establishing toxic limits by the analysis of field samples. Thus No. 3 gave 0,22 percent black alkali where there was 25 percent crop only a few feet from bare land; and No. 2, with only half as much alkali, supported almost no crop. If we consider the group as a whole, it seems probable that in the field under otherwise favorable conditions feterita on this type of soil will tolerate 0.06 percent black alkali without serious injury, but that 0.1 percent would be prohibitive for profitable cultivation. Barley shows greater resistance and No. 18 shows full growth with 0.153 percent sodium carbonate by analysis. On the other hand, No. 17 shows marked injury with 0.017 percent, but here the injury is due to soluble salts, chiefly sodium sulphate. There is no apparent reason, based on the analyses, why Nos. 15 and 16 should have produced only half a crop.

Other data on the resistance of crops to alkali under field conditions as determined by us will be found in the Twenty-ninth and the Thirtieth Annual Reports of this Station on pages 342 and 408, respectively. The latter reference deals exclusively with cotton on Salt River Valley soils, which for the most part were saline rather than black alkaline.

TABLE VIII.—TOLERANCE OF FETERITA AND BARLEY FOR ALKALI AT UNIVERSITY FARM

No.	DESCRIPTION	Soluble solids	Chlorides as sodium chloride	Black alkali sodium carbonate	Nitrogen total
	FETERITA, 1915	Percentage	Percentage	Percentage	Percentage
1	A few scattered stalks barely existing.	.50	.012	.153	
2	Almost extinct	33	.008	.119	
3	25 percent crop, 10 ft. from bare ground	.32	.008	.220	
4	25 percent crop	.49	.012	.119	
5	Better than No. 4 (35%)	.23	.008	.059	
6	50 percent crop	.24	.008	.042	
7	Good growth	.30	.008	.064	
8	75 percent crop	.22	.008	.017	
9	1 ft high, 15 ft. from No. 8	.49	.008	.169	
10	100 percent crop	.32	.008	.034	
	BARLEY, 1916				
11	No crop	.76	.036	.288	.045
12	No crop, surface white	1.26	.120	.288	.050
13	No crop, surface white	.92	.104	.254	.040
14	5 percent crop	.48	.012	.204	.040
15	50 percent crop	.31	.008	.059	.091
16	50 percent crop	.24	.008	.068	.048
17	50 percent crop	1.23	.132	,017	.068
18	100 percent crop	.27	.008	.153	.033
19	100 percent crop	.31	.008	.068	.058
20	100 percent crop	.24	.004	.068	.068
21	100 percent crop	.40	.010	.008	.083
22	100 percent crop, surface white, 2 ft. from No. 13	.78	.104	.102	.052

IN POT CULTURES

By means of pot cultures, however, in which all accompanying conditions are controlled and only the amount of black alkali allowed to vary, consistent results are obtained. As stated elsewhere, we have determined in this manner the tolerance for black alkali of Sonora wheat and common 6-row barley. Winter crops, especially the small grains, are much better adapted for pot cultures in this climate than summer crops. We have determined, however, with some degree of satisfaction the tolerance of cotton and tepary beans,[1] but these plants have not been studied so thoroughly as the winter grains which we are using as indicators of soil conditions rather than as primary subjects of investigation.

Method of Determining Alkali Tolerance:—Alkali tolerance is determined with a series of soils of uniform texture containing 0.05, 0.10, 0.15, 0.20, and 0.25 percent sodium carbonate by analysis. One or two tons of moderately black alkali soil, as low in salinity as can be found, is dried and mixed repeatedly. Two other soils of similar texture, one high, the other low in black alkali, are also selected and prepared in the same way. The main stock soil is then blended with the stronger or the weaker black alkali soil to give the exact alkalinity desired. The chlorides and sulphates are determined and the series brought to uniform salinity corresponding to the most saline mixture. Finely ground bone ash and potassium nitrate are added to each blend in suitable equal amounts to eliminate any differences in fertility between the stock soils. Ten kilograms of soil are used for each culture.

The 10-inch flower-pots are thoroughly paraffined to prevent the absorption or escape of alkali and consequent reduction of its concentration. A glass drainage tube is paraffined into the hole on the bottom of the flower-pot and passes through a hole bored in the bottom of the compartment bench. A bottle beneath the bench catches any leachings, which are again returned to the soil. Each flower-pot is in fact a small lysimeter. The benches are buried so that the tops of the flower-pots are level with the ground. Each complete bench contains a row of compartments on both sides with a space between sufficiently wide for a man to pass along and empty the bottles that catch the drainage. When not in use this areaway is covered tightly so as to maintain a uniform temperature throughout the series of pot cultures. The details of the device are shown in figure 3.

For pot cultures a pure strain of Sonora wheat was available; in some series of cultures seed from one or two mother plants was used. This variety is well acclimated to drought and alkali, and in high concentration of alkali invariably makes better growth than barley. The barley used was the ordinary 6-row, and was selected much less carefully than the wheat. Eight or ten seeds were planted, and the seedlings, when

[1]The toxic limit for cotton in University Farm soil appears to lie between .10 and .15 percent sodium carbonate by analysis. At .25 percent a single seed germinated, but the plant soon died. Tepary beans also appear to have a limit of tolerance between .10 and .15 percent in this soil. At .25 percent there was no germination; at .20 percent some germination, but the plants died when 2 or 3 inches high. Milo and hegari also showed a tolerance of about .15 percent, but failed entirely on .25 percent sodium carbonate. At .20 percent milo also failed entirely, but hegari made a slight growth.

well established, were thinned to four. After the toxicity of the alkali is removed as the limiting factor, the size of the pots determines the amount of growth. However, the assumption, therefore, that when the yields no longer increase with diminished alkali concentration the alkali is no longer toxic may not be strictly correct.

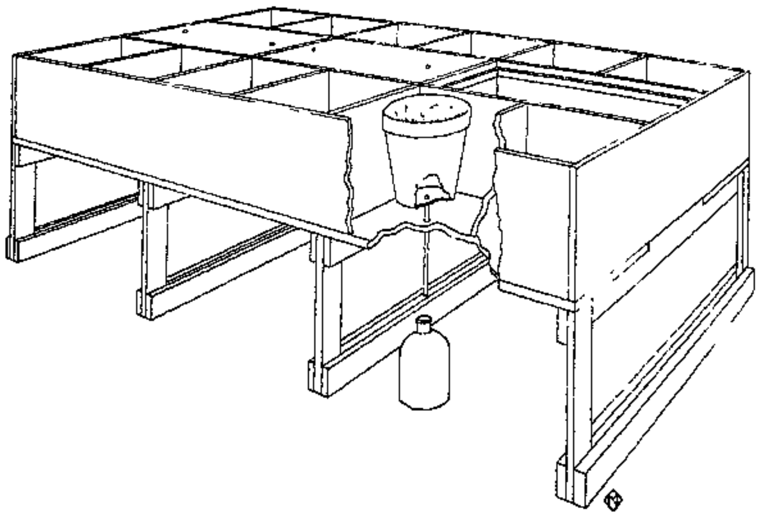

Fig. 3.—Compartment bench for pot culture experiments.

Alkali Tolerance in Pot Cultures:—Table IX shows the average yield of dry matter of wheat and barley in pot cultures with different black alkali content. Each result is the average of six pots placed in sets of two in different compartment benches. The grain yields in the strongly alkaline pots were mostly shrivelled and blasted. The figures given in Table IX are for a single year's cultures, but repetition of the determinations in other seasons gave substantially the same result. The effect of the alkali was more striking to the eye in the height, general vigor, size of head, and color of the plant than are the tabulated figures. The 0.075 percent concentration in the barley series was displaced by 0.30 percent, which prevented germination. The yield of straw and grain as shown by weights increased up to 0.05 percent sodium carbonate, but at 0.15 percent the plants seemed to be doing well and the grain that formed was plump. Sonora wheat withstood high concentrations of black alkali much better than did the barley, but at lower concentrations the barley is more productive than the wheat. The low yield of grain in the 0.05 percent black alkali cultures in the barley series is striking. Possibly it may be accounted for by the fact that leached soil was used for the low concentrations as we were unable at the time to find any sufficiently low black alkali soil of the same texture. Since both grains showed severe injury at 0.20 percent black alkali, yet made some growth, this concentration has been selected by us as the working toxic limit at which the influence of different treatments can be studied advantageously, there being always some yield with the untreated check plots for comparison.

TABLE IX—YIELDS OF WHEAT AND BARLEY IN DIFFERENT CONCENTRATIONS OF BLACK ALKALI IN POT CULTURES

Black alkali	Wheat			Barley		
	Straw	Grain	Total dry matter	Straw	Grain	Total dry matter
Percentage	Grams	Grams	Grams	Grams	Grams	Grams
.25	1.33	.34	1.67	0.0	0.0	0.0
.20	5.54	1.54	7.08	4.19	1.21	5.40
.15	6.20	2.13	8.33	7.86	2.50	10.36
.10	6.32	2.43	8.75	12.41	2.47	14.88
.075	9.46	3.21	12.67	Out	Out	Out
.05	8.51	3.49	12.00	15.90	.43	16.33

CHARACTER OF THE GROUNDWATER AT UNIVERSITY FARM

The groundwater at the University Farm belongs to the Rillito underflow lying north and east of Tucson, which is of entirely different character from the waters of the Santa Cruz underflow, lying south and west of the city. In past years the waters of the Rillito underflow have been almost invariably slightly black alkaline[1], containing very little salt and totally dissolved solids. Those of the Santa Cruz have always been of the opposite character, containing calcium sulphate, instead of sodium carbonate, and more salt and dissolved solids than the Rillito waters. With heavier drafts on the Rillito underflow in recent years, the Santa Cruz waters are being drawn more and more into the former Rillito reservoir. Table X records analyses of 10 water samples representing the underflow in the region of the University Farm, December, 1922. The analyses indicate that no undesirable waters occur in the immediate neighborhood of the farm. The dissolved solids are seldom lower in any waters found in the State and the salinity is negligible. They do not show, however, a sufficiently important amount of calcium and magnesium salts to tend strongly to counteract the black alkalinity of such soil as that of the University Farm. It is possible that with continued heavy pumping these waters will gradually become harder in character. We may say, however,

[1]Analyses made in this laboratory and reported by Smith, Ariz. Sta. Bull. 64, p. 93

with confidence that during the period covered by these experiments the irrigating water not only has not assisted in neutralizing black alkali, but on the contrary has tended to aggravate the black alkali condition of our plots.

GYPSUM RESOURCES OF ARIZONA

As a compensation for the large areas of black alkali soil within the State, Arizona, fortunately, possesses almost unlimited supplies of high grade gypsum Many irrigating waters carry in solution large amounts of gypsum or its equivalent in magnesium salts Such waters are the natural antidote for black alkali, and it seldom if ever accumulates where they are available Many deep drilled wells have encountered thick layers of gypsum, forming parts of old lacustrine deposits Beds of gypsum of greater or less extent are known in many parts of the State and probably most of our important agricultural districts have deposits within reasonable distance.

As early as 1896 Dr. Wm P Blake, Professor of Geology at the University of Arizona, published a paper entitled, "Gypsum in Arizona"[1] and later the Arizona Bureau of Mines published a bulletin on the same subject[2] From these sources we learn that gypsum occurs in Navajo Count) on Fort Apache Reservation, at Snowflake, Winslow, and Woodruff The Wmslow deposit is stated to have been quarried since 1909 In Cochise County gypsum occurs at Douglas and has been worked since 1903 The Arizona Gypsum Plaster Company of Douglas manufactures gypsum wall plaster and has available excellent gypsum for agricultural purposes (See Fig 4). In Pima County gypsum occurs m the Santa Rita and Santa Catalina mountains The latter deposit was the source of the gypsum used m these experiments. In Pinal County about 6 miles south of Winkelman occur deposits from 10 to 75 feet m thickness and analyzing over 99 percent gypsum These deposits controlled by the Arizona Gypsum Company have not been worked, but are reported by the United States Geological Survey to be the largest and most extensive deposits of high grade gypsum m the United States.

CHARACTER OF GYPSUM AVAILABLE NEAR TUCSON

The deposit m the foothills of the Santa Catalina Mountains lies m a small ancient lake bed several hundred feet above the Rillito Valley in which the University Farm is located The haul of 3 or 4 miles is thus mostly down grade. Several hundred loads of loose, soft gypsite are

[1]Amer Geol, Vol 18, p 394
[2]Ariz Bur of Mines, Bull 19, by Frank L Culm, Jr

TABLE X—CHEMICAL CHARACTER OF GROUNDWATERS IN RILLITO VALLEY NEAR THE UNIVERSITY FARM, PARTS PER 100,000

Lab No	Name	Location	Soluble solids	Chlorides as sodium chloride	Temporary hardness, as calcium bicarbonate	Permanent hardness, as calcium sulphate	Black alkali, as sodium carbonate	Calcium	Magnesium	Sulphite (ions)
8,607	University Farm	S E ¼ Sec 19, T13S, R14E	23.6	1.8	13.0	neutral	neutral	6.0	4	3.9
8,608	Baker's Ranch	N W ¼ Sec 19, T13S, R14E	24.8	2.4	12.2	——	1.69	4.8	4	6.8
8,609	Shallow well 1 mile west	N % Sec 24, T13S, R13E	24.0	1.8	13.0		.42	6.0	trace	4.0
8,610	H E Finis	N E ¼ Sec 24, T13S, R13E	31.2	2.2	16.2	2.72		7.2	trace	5.4
8,611	Wetmore's Park	N E ¼ Sec 24 T13S R13E	25.5	2.0	14.6	9.18	——	6.6	trace	4.5
8,612	Pastime Park	N W ¼ Sec 25 T13S R13E	33.6	2.8	16.1	——	.85	7.2	trace	6.0
8,613	Frank Howe	N E ¼ Sec 2S T13S R13E	24.6	2.6	13.0	1.09	——	3.9	trace	3.6
8,614	Vic Griffith	S W ¼ Sec 29 T13S R14E	38.4	fi4	13.0	——	.54	4.5	trace	9.7
8,615	Judge Sawtelle	S W ¼ Sec 25, T13S, R13E	18.8	2.2	9.7	neutral	neutral	4.2	trace	5.7

available on the surface, and several overlying strata of massive alabaster, each a foot or more thick, may be quarried and ground when the surface gypsite is exhausted. Clay layers interspersed with veins of satin spar are associated with the alabaster. The gypsum content of the various materials calculated from the total sulphur present is given in Table XI.

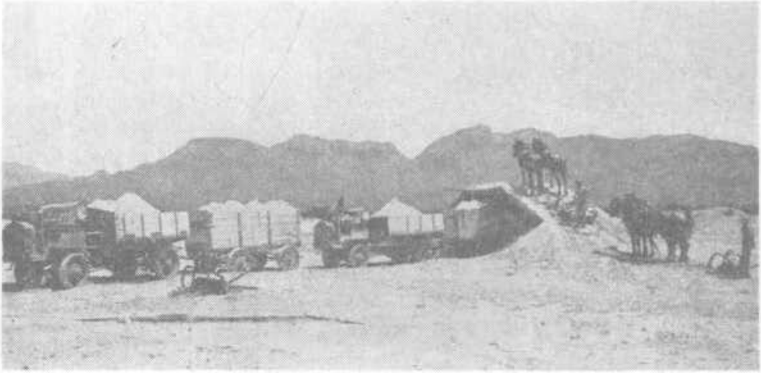

Fig. 4.—Loading and hauling gypsum at Douglas, Arizona.

CROP HISTORIES OF THE BLACK ALKALI PLOTS, 1915 TO 1919

The lands used for these experiments were leveled in 1913, but no crop records were kept during 1914. During the summer of 1915 a crop of feterita that was almost a total failure was grown and mapped, November 15. At that time the plots were more extensive and eight in number, but in 1916 a road was cut through the tract and all of lands, 30, 31, 32, 33, and half of Land 34 taken for other purposes. At that time a new land was leveled and cropped as a check, being designated Land 38. The portion of the crop maps published in this bulletin are

TABLE XI.—COMPOSITION OF GYPSUM FOUND NEAR TUCSON AND USED AT UNIVERSITY FARM, AIR DRIED.

Lab. No.	Description of Sample	Hydrous calcium sulphate calculated from total sulphur
		Percentage
6,387	Massive alabaster	94.68
6,389	Gypsite, soft, weathered gypsum with earth	71.33
6,390	Clay impregnated with gypsum and veins of satin spar—the latter removed as far as possible	59.44

only those retained through the entire experiment, with the exception of Land 34, which appears on the two earliest maps. The crop maps were drawn by laying off the lands in 50-foot sections which were marked with a surveyor's range pole, easily seen above the crop. For convenience in orientation these sections are shown on the maps. The best growth on the tract—a part of the north end which was fairly free from alkali and which supported a normal crop—was taken as the standard and called 100 percent production. The relative production was judged by the mapper and not determined by actual weighings. The changes in the condition of the crop were not so abrupt as shown on the maps, yet substantially as indicated.

The crop map for feterita in 1915, (Fig. 5) shows the greater part of the tract to be bare with the exception of the north end, which supported from 50 to 75 percent crop with a small area of full standard production and a margin of light growth (25 percent) bordering on the bare land. A few spots of stunted feterita are shown at other places on the tract.

The frontispiece shows the north half of the same feterita crop. The heavier growth at the right was on land originally mapped, but later put to other uses. The vegetation in the left foreground is mostly black alkali weed. Later, Land 38 was leveled on this edge of the tract. The granitic Santa Catalina Mountains in the background are the source of a large part of the groundwaters of the district and probably give them their alkaline character.

The barley crop, May 2, 1916, is mapped in figure 6. Here conditions seem to be reversed. The crop at the north end of the plot is almost a failure, while something like 100 percent production was had at the south end. Barley is a resistant crop and it is probable that the south end of the plot received extra water. It is also significant that the poor barley, aside from that on the central, excessively alkaline area, is found where the preceding crop of feterita was heaviest. The deleterious effect of sorghums on winter grain crops which follow is a matter of common experience, as yet unexplained. It should be noted that on this map the barley is covering the more alkaline area, even though with a stunted growth, much better than did the feterita. Summer crops, however, are usually at great disadvantage on alkaline soil.

Corn followed the barley in 1916, and figure 7 shows the crop on September 15. The bare area is approximately the same as in the case of feterita. It will be noted, however, that the crop on the north end is back to normal, or even better than the previous feterita crop, the injurious effect of the sorghum, if such it be, having been overcome. Beginning with the corn crop in 1916, the new Land 38 was leveled and consequently Land 34 was dropped from the portion of the crop

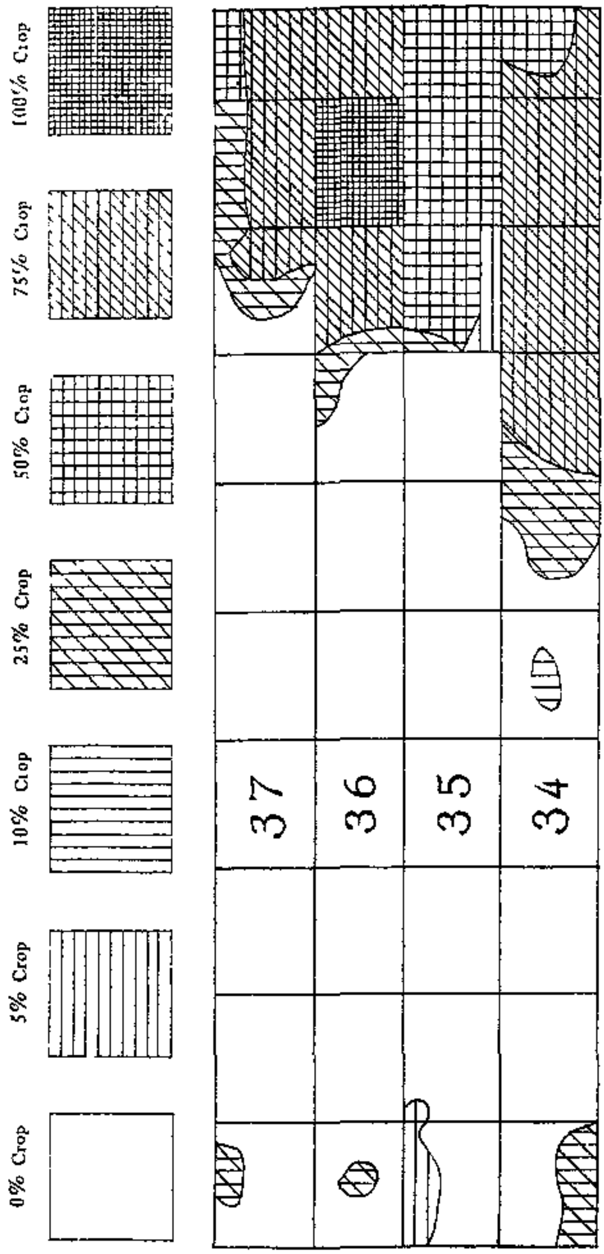

Fig 5.—Crop map of feterita on black alkali plots, November, 1915

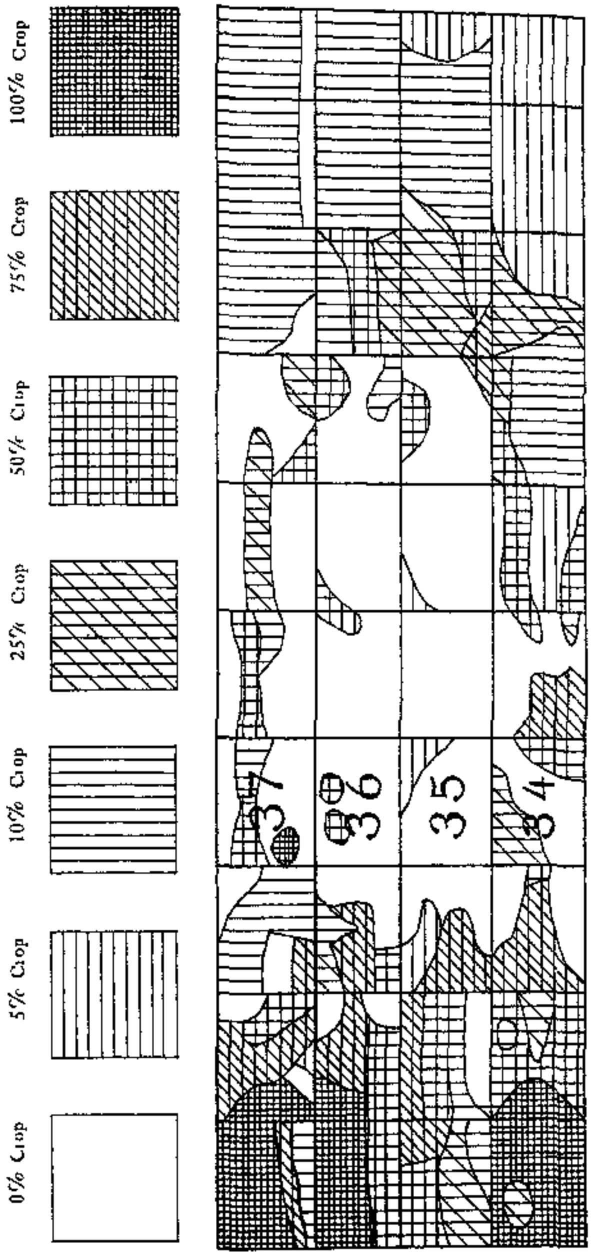

Fig 6.—Barley following feterita on black alkali plots, May, 1916

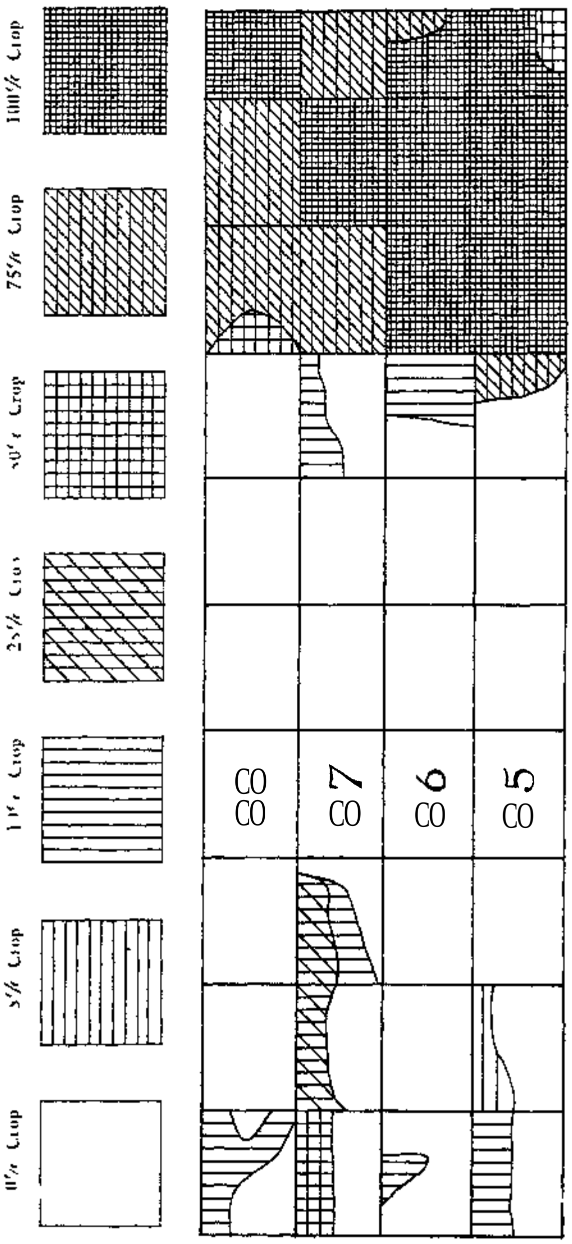

Fig. 7.—Corn on black alkali plots, September, 1916

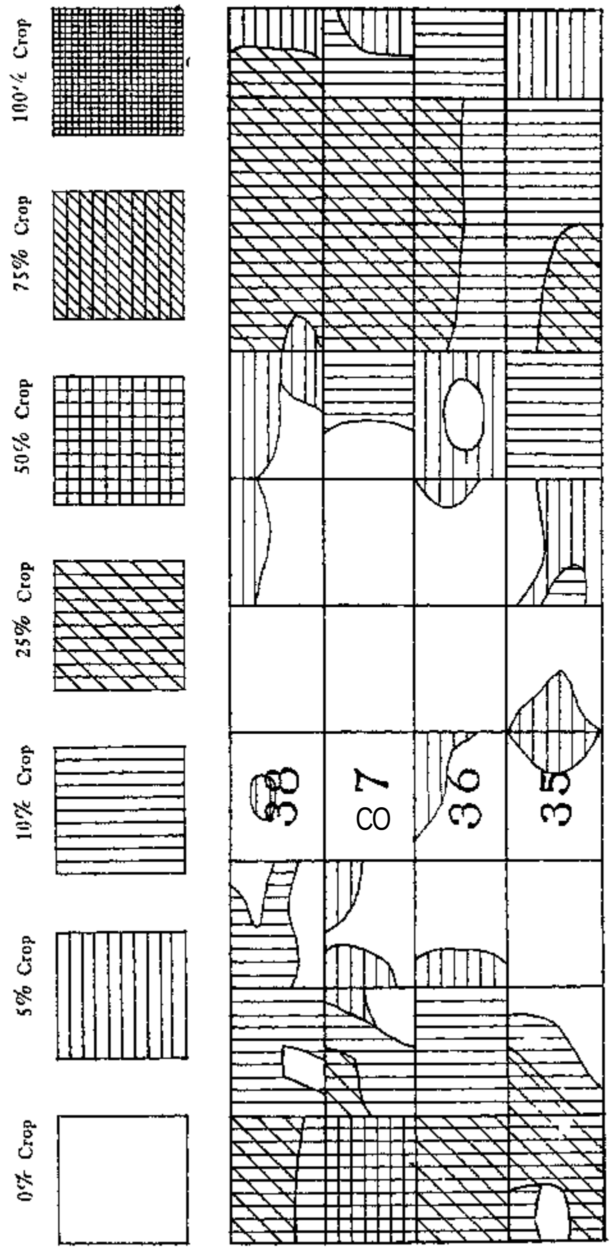

Fig. 8.—Barley on black alkali plots, May 30, 1917

maps that have been reproduced for this bulletin. Immediately preceding the corn crop this year, a variety of treatments were given the lands in the tract by the agronomist, the tract at that time not having been designated definitely for gypsum treatment studies. A record of the treatment given all the lands including those later discarded for this experiment is found in the Twenty-seventh Annual Report of the Arizona Agricultural Experiment Station, page 296. Of the lands retained, Land 35 received 400 pounds of acid phosphate and 20 tons of manure; Land 36 received 500 pounds of acid phosphate; Land 37, 400 pounds of quicklime to flocculate the soil; and Land 38 was to have received 500 pounds of Chili saltpeter in three applications, only one of which was given. None of these treatments would have any appreciable influence on the black alkali with the exception possibly of the 20 tons of manure, the acid phosphate application being so light in comparison to the sodium carbonate present as to be negligible.

The crop map for barley, May 30, 1917, (Fig. 8) shows improvement over the crop in 1916 on the north end, but other parts of the plots on the whole were not so good.

Corn followed barley during the summer and fall of 1917, and as shown by the crop map, (Fig. 9) was a failure except a few small areas on the less alkaline north end. The bare land at the extreme north end was due to cultural reasons and not to alkali.

RECLAMATION OF BLACK ALKALI LAND AT UNIVERSITY FARM

GYPSUM TREATMENT IN 1919

No crop maps were made in 1918, but the tract was sampled thoroughly and systematically to determine the amount of gypsum needed to neutralize the black alkali. This was done by laying the lands off

TABLE XII—YIELDS OF WHEAT AND BARLEY ON BLACK ALKALI PLOTS, 1922 POUNDS PER ACRE

		No treatment west side Land 34	Gypsum 10 tons Land 35	Gypsum 10 tons, manure 20 tons, leached 12 hours Land 36	Gypsum 10 tons, manure 20 tons, unleached Land 37	Manure 20 tons, Land 38
Barley	Straw	1,825	1,721	4,319	5,243	3,722
	Grain	349	698	2,491	2,581	927
	Total	2,174	2,419	6,810	7,824	4,649
Wheat	Straw		2,065	4,906	5,608	2,258
	Grain		748	2,268	2,080	959
	Total		2,813	7,174	7,688	3,217

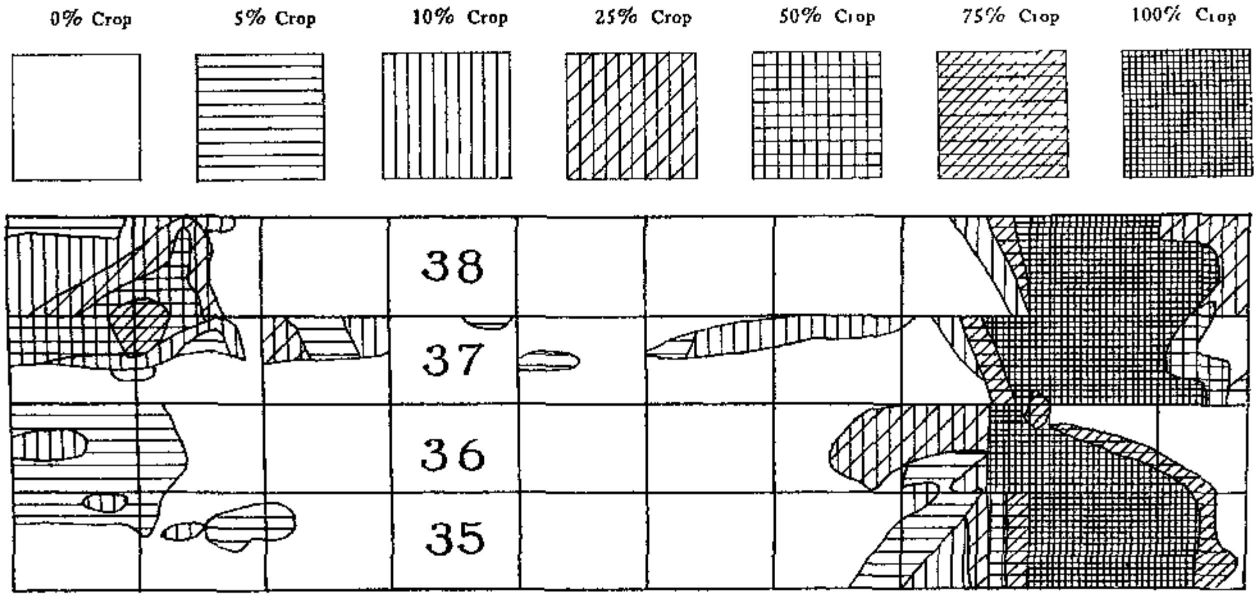

Fig. 9.—Corn on black alkali plots, October, 1917

in 50-foot sections similar to those used in making the crop maps. Composite samples of the first, second, and third feet from five bore holes were analyzed and the gypsum equivalent calculated. From 500 to 3,000 pounds per 50-foot section were required. Sorghum was planted in 1919, and the crop map is given in figure 10. A marked improvement in the crop is shown especially as regards the amount of bare land. A considerable part of this was now covered with a stunted growth, but the tract as a whole was still far from being satisfactorily reclaimed.

GYPSUM AND MANURE TREATMENT IN 1920

The treatment in 1919 appearing to have been beneficial but insufficient, in 1920 the lands were resampled and the following treatments given: Land 35, 500 to 2,500 poundb of gypsum per 50-foot section; Land 36, similar amounts of gypsum and 20 tons of manure to the acre, followed by leaching, the water being held by dykes every 75 feet for 12 hours, Land 37, the same gypsum and manure applications as on Land 36, but only regular irrigation; Land 38 was given 20 tons of manure. The gypbum and manure were spread evenly and the land was then disked and irrigated. When in proper condition the land was plowed 10 inches deep with a tractor and planted to corn. Figure 11 gives the map for this crop, which was cut for silage September 21, 1920. The central, formerly bare area, is now seen with a 50 to 75 percent crop, but Land 38 that has never received gypsum is still mostly bare. This may have been due in part to cultural reasons, but the following barley crop was also a failure on thib plot.

The corn was followed in the fall of 1920 by barley without further treatment. The crop was pastured, due to shortage of feed. While no satisfactory crop maps could be drawn under the circumstances, the photograph reproduced in figure 12 shows a good growth of barley on Land 37 and shows Land 38 to be almost bare.

After the 1920 treatment had been applied, it was discovered that much of the gypsum used had been of very low grade. Nevertheless, the barley crop was followed in 1921 by hegari without further treatment. This crop was almost a complete failure, and analyses showed that no gypsum remained in the surface foot, all having been neutralized by alkali from below.

GYPSUM AND MANURE TREATMENT IN 1921

During the fall of 1921 the same treatments with gypsum and manure as given before were repeated, consisting of approximately 10 tons of gypsum and 20 tons of manure to the acre. In the meantime we had noticed in pot cultures the marked alkali-resistant character of Sonora

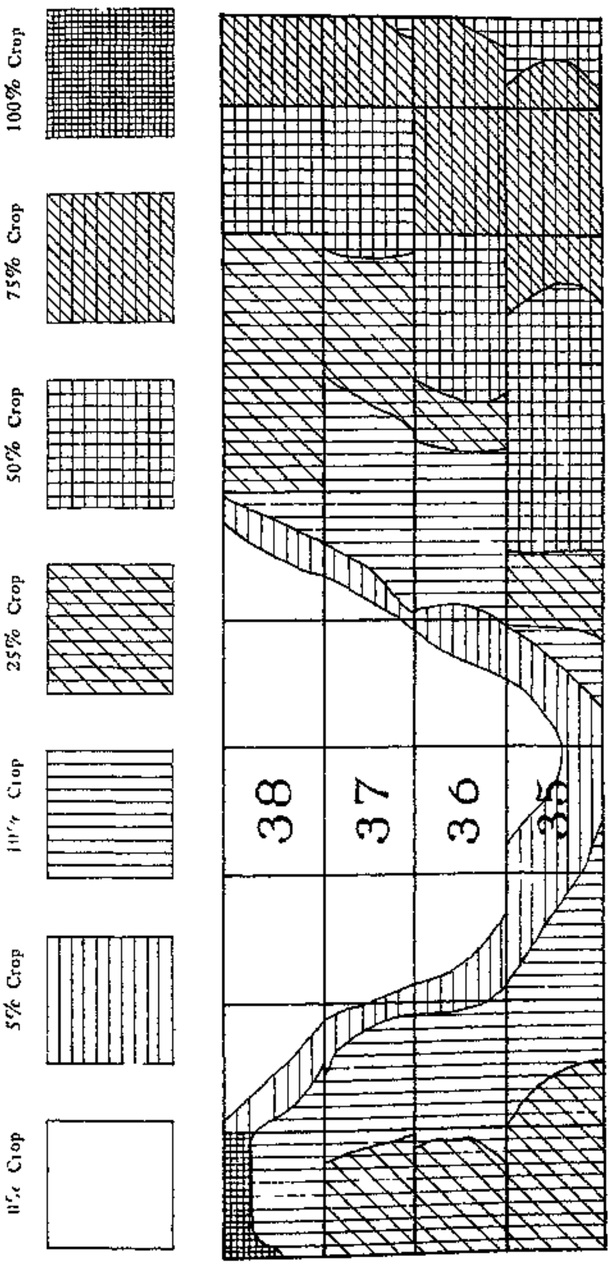

Fig. 10.—Sorghum on black alkali plots after gypsum treatment, September, 1919.

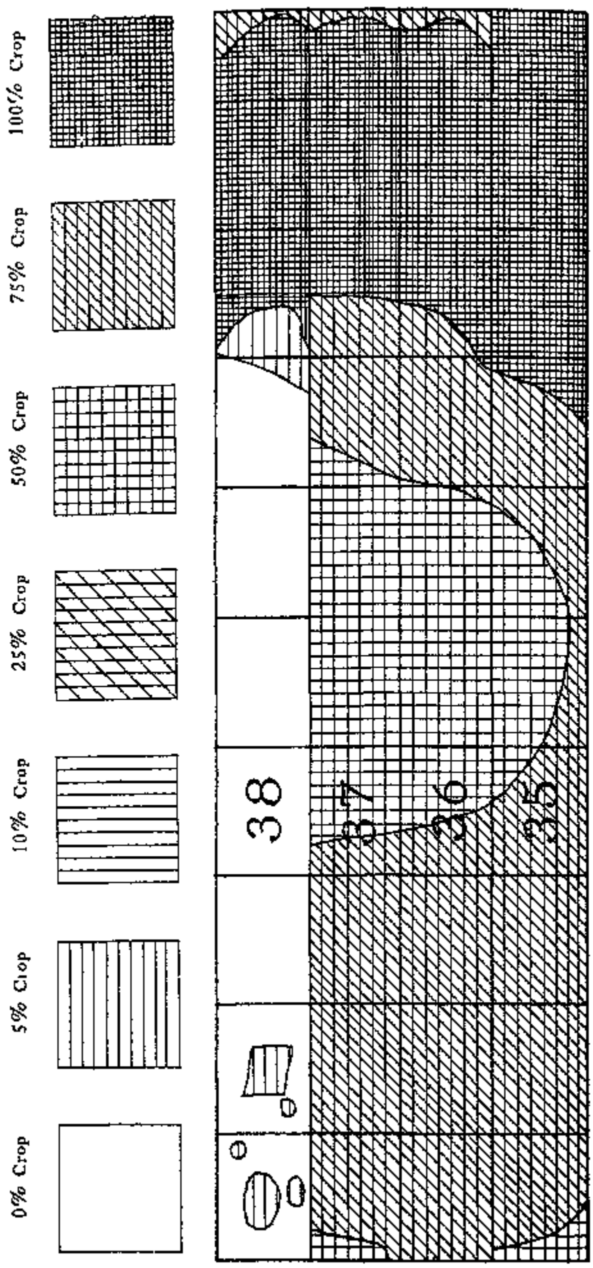

Fig 11 —Corn after gypsum and manure treatments, September, 1920 wheat, and consequently, the plots were divided longitudinally, half the plot being planted to Sonora wheat and the other half to common 6-row barley. The only check plot available was the west side of Land 34, which had received no treatment for several years, but probably yielded better than would the other lands of the series, since the central bare spot on this land was originally smaller than on those to the westward. At harvest time photographs were taken of the several plots, and hoop samples were weighed and thrashed to estimate the yields. The stands of grains obtained by the different treatments are shown in figures 13 to 21. The yields of straw and grain are recorded in Table XII.

A study of Table XII shows that with barley both gypsum and manure caused an increase in yield especially noticeable in the grain.

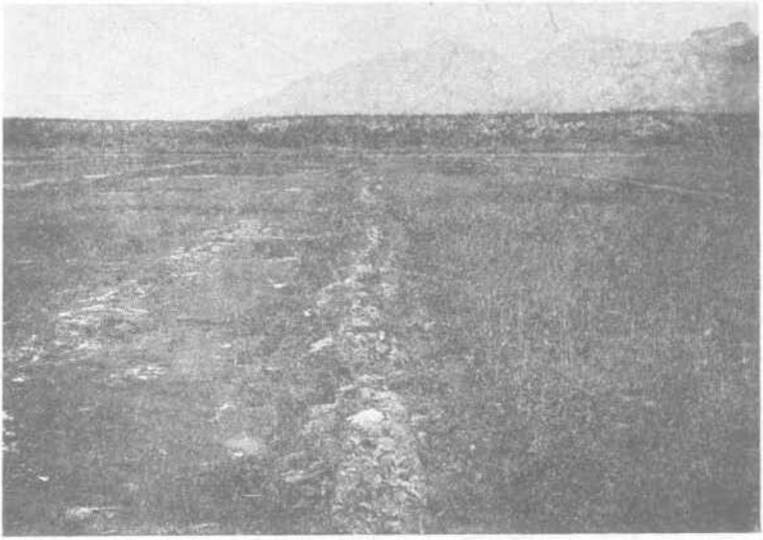

Fig. 12.—Barley on Lands 37 and 38, February, 1921. Land 37 had received 10 tons of gypsum and 20 tons of manure before the previous corn crop, and Land 38 had received 20 tons of manure. Pastured during the winter.

Gypsum did not tend to produce straw, but on the manure plot the increase in straw yield was relatively much larger than the increase in grain. The combination of gypsum and manure produced more straw and much more grain than the sum of the crops yielded by the treatments applied singly. Leaching on this soil did not change the grain yield materially but caused a large reduction in the yield of straw. Substantially the same results are shown on the wheat plots as with the barley. As noted elsewhere, Sonora wheat produces heavier in pot cultures on strongly alkaline soils than does barley, but ordinarily barley is recognized as a heavier producer than wheat. Here Sonora wheat has produced more grain under the separate treatments with gypsum and with manure than has barley. Under the combined treatment barley will probably be found to average more grain than will wheat. Barley shows a marked stimulation of straw over grain production with manure.

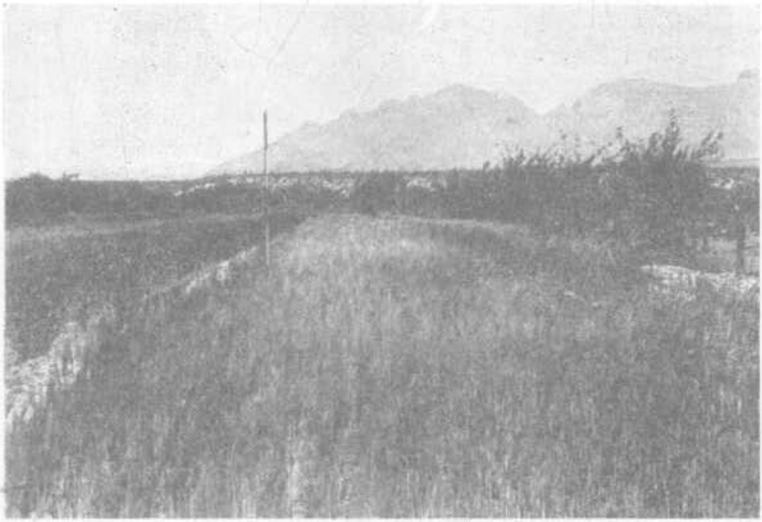

Fig. 13.—Barley on moderately strong black alkali soil, Plot 34, 1922. Yield, 349 pounds of grain per acre.

A comparison of the grain yields on lands 36 and 37 receiving gypsum and manure with similar crops grown on the sweet soil of the Salt River Valley Farm at Mesa in 1922 is decidedly to the advantage of the reclaimed alkaline land. The average yield of grain for 19 acres of 6-row barley at Mesa was 1,945 pounds per acre; the average on black alkali lands treated with gypsum and manure was 2,536 pounds per acre, an increase of 30 percent. The average for all varieties of wheat at Mesa in 1922 was 1,680 pounds per acre; the average for Sonora wheat on the gypsum and manure treated lands was 2,174 pounds per acre, an increase of 29.4 percent.

Following the barley and wheat, Mexican June corn was planted on the alkali plots in July, 1922. The crop was cut for silage and the gross weights of the green corn are recorded in Table XIII. It would seem according to the weights that the effect of the manure was rapidly wearing off, since lands 35 and 37 produced the same, and Land 38 that has always received manure alone produced scarcely half a crop. Land

36 that had been leached before the barley and wheat crop shows a decidedly larger corn crop than any of the unleached soils.

After the removal of the corn crop three of the treated lands were sampled to depths of 6 feet, November 17, 1922. The analyses of the samples are given in Table XIV. The plot treated with manure alone is still excessively black alkaline in the first 3 feet. The plot on which both manure and gypsum were used contains a large excess of gypsum in the first and third feet. The second and fourth feet are still strongly black alkaline. The plot on which gypsum alone was used shows the surface foot neutral with the subsoil all strongly black alkaline. The analyses on the whole seem to show, as has been found elsewhere, that gypsum does not penetrate readily into the subsoil. On the other hand the crops produced on this land, taken in conjunction with the analyses, prove very definitely that unusually good yields may be obtained if enough gypsum is maintained in the surface foot to neutralize any alkali that may rise from below and keep the soil well flocculated so that it takes water readily. Under these conditions it appears that rather large amounts of black alkali may be tolerated in the subsoil by ordinary grain crops.

USE OF MANURE IN RECLAIMING BLACK ALKALI LAND

These experiments afford very positive information regarding the benefits and limitations in the use of manure in handling alkali, especially

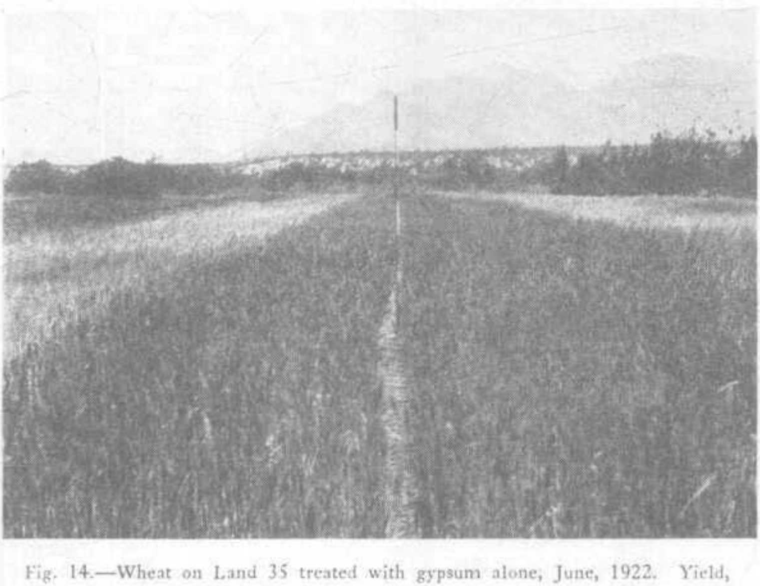

Fig. 14.—Wheat on Land 35 treated with gypsum alone, June, 1922. Yield, 748 pounds of grain per acre.

black alkali. In this they confirm the reported experience of farmers and the pot cultures carried on by Lipman and Gericke.[1] These authors found that the resistance of barley to the toxic effects of alkali was much enhanced by the presence of organic matter in the form of manure.

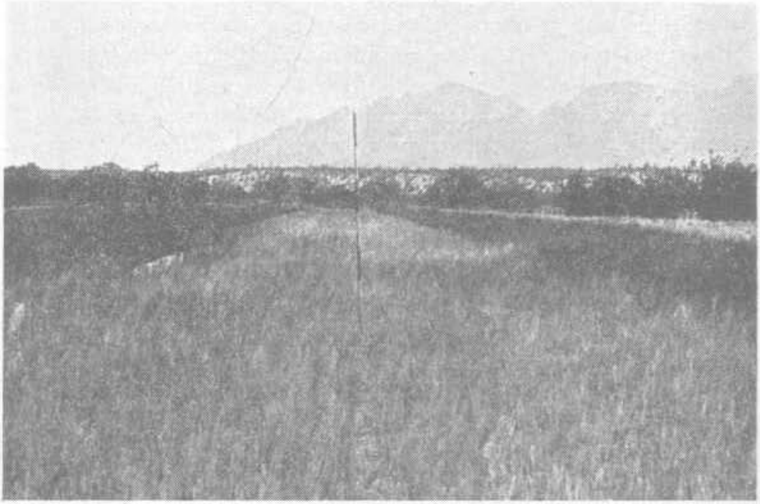

Fig. 15.—Barley on Land 35 treated with gypsum alone, June, 1922. Yield, 698 pounds of grain per acre.

They found the result to hold for sodium chloride, sulphate, and carbonate, and to be more marked as the amount of manure was increased. With 40 to 60 tons of manure per acre, barley was as productive in 0.6 percent sodium chloride or sodium sulphate soil as in soil that had no alkali added. As was to be expected, that concentration of sodium carbonate prevented the germination of the grain the first year, but similar results to those obtained with chloride and sulphate were obtained with 0.3

TABLE XIII.—YIELDS OF MEXICAN JUNE CORN CUT FOR SILAGE ON BLACK ALKALI PLOTS, 1922.

Land	Treatment	Yield
		Lbs. per acre
No. 35	Gypsum, 10 tons	7,662
No. 36	Gypsum, 10 tons; manure, 20 tons, leached	11,322
No. 37	Gypsum, 10 tons; manure, 20 tons, unleached	7,619
No. 38	Manure, 20 tons	3,810

[1]The Inhibition by Stable Manure of the Injurious Effects of Alkali Salt in Soils. Soil Sci., Vol. VII, No. 2.

percent sodium carbonate (added to the soil and not by analysis). They also observed that the beneficial effect of the manure "wore off" with succeeding crops, and more rapidly where the lesser amounts were used.

In all cases there appears to be little doubt that manure is of great benefit in handling alkali, but much doubt exists as to the chemical and physical mechanism of its action. Lipman and Gericke attribute the effect to colloidal phenomena by which the injurious salts are absorbed and their concentration in the soil solution lowered. In conversation with the writers, Dr. W. P. Kelley of the Riverside Station has suggested the possibility that the effect is due to carbon dioxide's changing sodium carbonate to bicarbonate, which is less toxic and may be leached more readily. In like manner any alkali-resistant, vegetative covering such as Bermuda or Rhodes grass should assist in handling black alkali.

TABLE XIV.—SOLUBLE SALTS AND CALCIUM CARBONATE IN BLACK ALKALI PLOTS AT UNIVERSITY FARM, NOVEMBER, 1922.

	Soluble solids	Chlorides as sodium chloride	Calcium sulphate	Black alkali as sodium carbonate	Calcium carbonate*
	Percentage	Percentage	Percentage	Percentage	Percentage
Land 38, manuie alone					
1st foot	.80	.088		.27	4.3
2nd foot	.70	064		.254	4.3
3rd foot	.64	060		.254	5.5
4th foot	.28	020		.169	3.5
5th foot	.27	.020		.085	2.9
6th foot	,27	.020		.034	6 3
Land 37, gypsum and manuie					
1st foot	.87	.024	.109		4.2
2nd foot	.63	.024		.220	4.2
3ıd foot	.45	.024	.065		4.2
4th foot	.50	.032		.254	4.8
5th foot	.31	.036		.102	4.2
6th foot	.44	.060		.119	6.9
Land 35, gypsum alone					
1st foot	.34	.016		neutral	6.8
2nd foot	.49	.016		.254	5.0
3ıd foot	.42	.040		.186	4.4
4th foot	.36	.008		.204	3.7
5th foot	.36	.044		.051	4.9
6th foot	.66	.022		.119	7.6

*Calculated from total carbon dioxide without deduction for sodium carbonate.

From an observation inadvertently made by us, it appears that the quality of the manure is also an important factor. On one of the plots treated with gypsum and 20 tons of manure, an abrupt stunting of the crop was noted that continued to the end of the land, although there never had been much alkali on that end of the plot. The crop appeared as if no manure had been applied, but the farm foreman stated that the cow manure used on the rest of the plots had been exhausted and that he had finished the border with manure from the horse stables. The cows were on heavy milk-producing rations and without doubt were producing very rich manure compared with that from the horse stables. Admittedly, this does not seem a sufficient explanation, for the plots were fairly well supplied with nitrogen before being manured, and this was the second time in 2 years that that plot had received 20 tons of manure to the acre.

The crop yields given in Table XII leave no room to doubt the efficacy of manure in handling black alkali when sufficient manure is

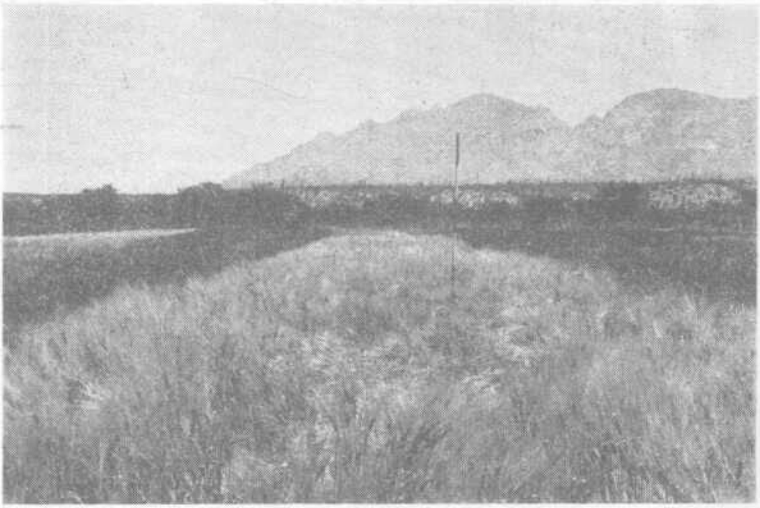

Fig. 16.—Wheat on Land 36 treated with gypsum and manure and leached 12 hours, June, 1922. Yield, 2,268 pounds of grain per acre.

applied. In 1920, Land 38 after receiving 20 tons of manure (quality not recorded) failed to produce barley and corn. It was only after treatment with an additional 20 tons in 1921 that the half crops of wheat and barley recorded in Table XII were obtained.

The short-lived effect of manure in counteracting the toxicity of black alkali is demonstrated clearly in Table XIII by the corn crop following the wheat and barley in 1922, although wheat and barley on Land 38 immediately following the application of a second 20 tons of manure produced very much heavier crops than those produced on Land 35 which received gypsum alone. The following corn crop was only half as large on Land 38 as on Land 35. Furthermore, Land 35 produced as much corn as did Land 37 that had received the same amount of gypsum

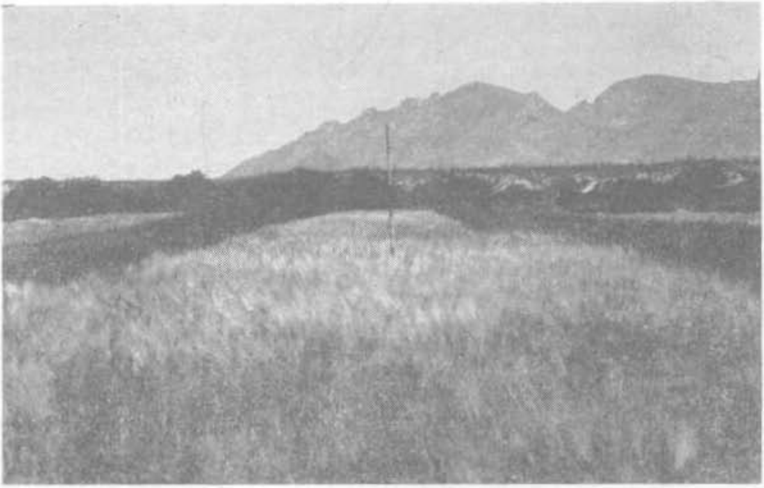

Fig. 17.—Barley on Land 36 treated with gypsum and manure and leached 12 hours, June, 1922. Yield, 2,491 pounds of grain per acre.

as Land 35 plus the same amount of manure as Land 38. The high yield of corn on Land 36 is not explained unless it be due to the previous leaching which did not show any special benefit to the preceding wheat and barley crops.

SUMMARY

The experiments at the University Farm prove unquestionably the possibility of controlling black alkali on that type of land by applying gypsum. We do not presume to say that the procedure would be profitable on large areas of strongly black alkali soil, but smaller areas that must be cultivated along with large areas of good land may bear very heavy expense for treatment, since they are not only absolutely worthless in themselves but detract from the value of adjacent, otherwise valuable lands and from the selling price of a farm.

Conditions at the University Farm are partly favorable, partly unfavorable for reclamation operation. As favorable, may be mentioned the light sandy character of the soil and probably its high calcium carbonate content. As unfavorable, may be mentioned the fluctuating water table, which it seems may occasionally force up fresh quantities of alkali from the subsoil. Further, little assistance is to be expected from any black alkali neutralizing compounds carried by the irrigating water, unless as seems possible, the character of the water may continue to change for the better.

By a combination of gypsum and manure, black alkali soil may be brought to a very high state of fertility, but the cost of treatment will be

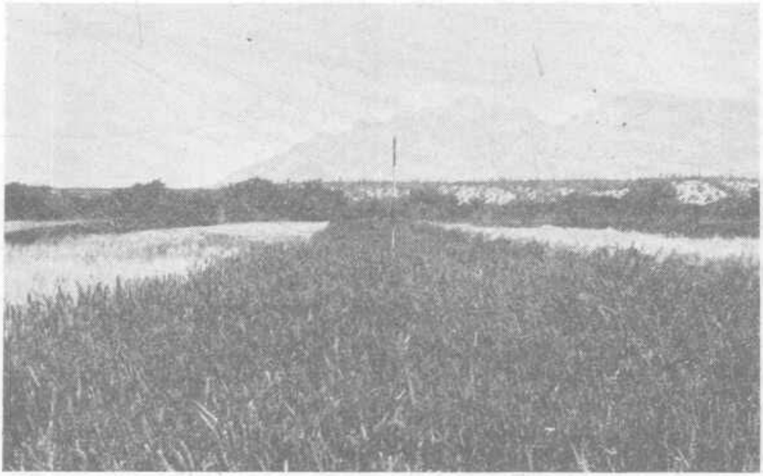

Fig. 18.—Wheat on Land 37 treated with gypsum and manure without leaching, June, 1922. Yield, 2,020 pounds of grain per acre.

high and under certain conditions it may have to be repeated. Although manure is very effective the amount required for any large area would be beyond the capacity of the farm to produce. Manure may find a place in getting a stand of alkali-resistant plants, such as alfalfa, that can tolerate fairly strong alkali when once established. The treatment with gypsum alone, or other chemical treatment, followed possibly by leguminous green manuring crops plowed under, seems the only practicable way of handling black alkali. The supply of gypsum being enormous and fairly well distributed, the price should decrease considerably with increased use, since large amounts may be handled at lower cost per ton. The increased productivity of land that is more or less black alkaline brought about by treatment with gypsum and other chemicals, making possible larger agricultural communities, might result in an increase of other business sufficient to warrant transportation companies in handling these commodities at a very low rate. By using teams and labor at the University Farm when work was slack, gypsum was put on the land for \$1.00 to \$1.50 per ton. Quotations, December 30, 1922, were \$3.40 per ton loaded in bulk in car lots f.o.b. Douglas, Arizona.

If the soil be saline, containing 0.5 percent or more of water soluble salts, including sodium carbonate, it will probably require some leaching after the gypsum treatment. But if salts other than sodium carbonate are not present in appreciable amounts and carbonate be moderate in amount, gypsum without leaching may be equally as good as with leaching. In pot cultures partial neutralization is often as good as complete neutralization, but in field practice where the gypsum cannot be mixed to a considerable depth, a fairly large excess of gypsum should remain in the surface foot. This will probably be carried into the subsoil slowly with the irrigating water, and certainly will neutralize any black alkali that may rise from the subsoil. By keeping the surface foot flocculated and open, a reservoir is formed which serves to hold a small head of water on the subsoil and force some percolation where otherwise none would occur. In any event, gypsum should be applied before leaching, because of its flocculating effect and preservation of soluble plant foods that otherwise would be carried away in the drainage.

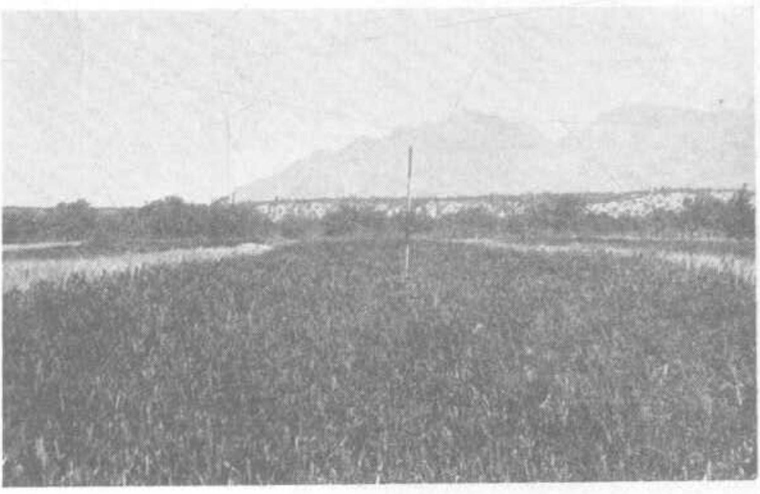

Fig. 19.—Barley on Land 37 treated with gypsum and manure without leaching, June, 1922. Yield, 2,581 pounds of grain per acre.

TREATMENT WITH CHEMICALS OTHER THAN GYPSUM

Chemicals other than gypsum would probably be equally effective, and several are produced in quantity as by-products of the mining and smelting industries of Arizona. Sulphuric acid is made at Douglas and could be produced in very large amounts there and at other smelters. Field experiments have been made at Casa Grande in which acre tracts were treated with this acid. At Ajo a by-product known as iron salts results in the recovery of copper from carbonate ores by leaching with sulphuric acid and precipitation of the copper with iron. These salts contain about three-fourths ferrous sulphate (ordinary copperas) and one-fourth aluminum sulphate. We have obtained very satisfactory re-

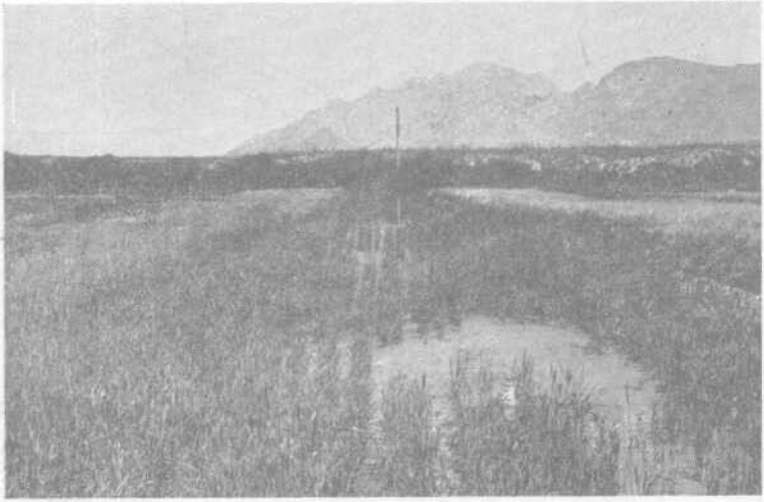

Fig. 20.—Wheat on Land 38 treated with manure alone, June, 1922. Yield, 959 pounds of grain per acre.

sults with ferrous sulphate in treating black alkali in pot cultures, and aluminum sulphate has been used successfully in field experiments in Nevada. Native deposits of aluminum sulphate may also exist in this State. It is entirely possible that sulphuric acid may be converted into alumiuum sulphate at the smelters for use in treating black alkali, this salt being more convenient to apply than the acid itself, and the base (aluminum) probably has some additional beneficial effect. Iron pyrites are available as a by-product in the concentration of certain copper ores, but in preliminary experiments we have not been able to bring about the oxidation of this material in the soil, at least rapidly enough to be of noticeable benefit. Elemental sulphur has been advertised as effective in treating black alkali. Pot cultures have shown some promise with ordinary flowers of sulphur, and several hundred pounds of "inoculated" sulphur were applied parallel with sulphuric acid in the field experiment at Casa Grande. All of these chemicals offer possibilities, but for lack of experimental data at this time we can recommend only gypsum. Undoubtedly some of the others will come into use, the extent of their use depending largely upon their price and effectiveness as compared with gypsum.

While this experiment has been very satisfactory and led to positive results, it should be repeated and expanded in scope on virgin black alkali land. Other chemical treatments should be compared and attempts made to substitute green manuring crops for barnyard manure.

CONCLUSIONS

1. Black alkali or sodium carbonate resists leaching tenaciously and can be removed from the soil successfully only after neutralization.

2. The black alkali problem is among the most important facing the arid Southwest, because of the toxic action of sodium carbonate and its deleterious effect on the penetration of irrigation water.

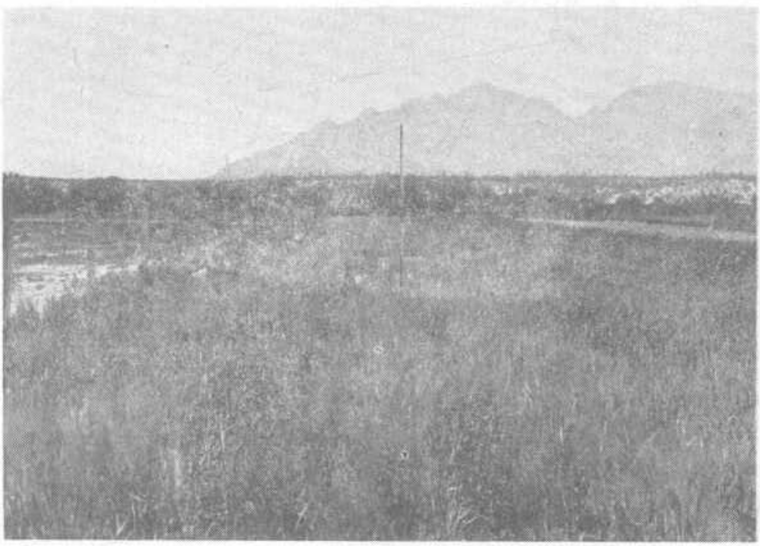

Fig. 21.—Barley on Land 38 treated with manure alone, June, 1922. Yield, 927 pounds of grain per acre.

3. The percolation of water through the University Farm soil, which is a very fine sand or fine sandy loam, is accelerated by gypsum treatment. The acceleration increases with the amount of gypsum applied, at least up to double that necessary to neutralize the black alkali present.

4. The chief forms of alkali present at the University Farm are sodium carbonate or black alkali, sodium sulphate, the least harmful form of white alkali, and unimportant amounts of sodium chloride or common salt.

5. Neutralization of the black alkali with gypsum before leaching causes a saving of plant food, the commercial value of which would pay a considerable part of the treatment.

6. The determination of the toxic limit of black alkali under field conditions is difficult. In some places plants are doing well in a concentration of alkali that is proving fatal nearby as determined by the analysis of soil samples taken at the plant roots.

7. Under field conditions as nearly as can be determined the toxic limit for black alkali of most crops in soil of the University Farm type appears to lie between 0.10 and 0.15 percent by analysis, the method of solution being an essential consideration in expressing the concentration.

8. A method of handling pot cultures with alkaline soils so as to keep concomitant conditions under control is described.

9. In pot cultures with high concentration by analysis, Sonora wheat proved considerably more resistant to black alkali than 6-row barley. Two-tenths percent sodium carbonate by analysis was selected as the working toxic limit at which various chemical treatments could be studied advantageously. Here also 0.15 percent proved to be the concentration at which wheat and barley failed to do fairly well.

10. The ground water at the University Farm is very free from salts and is neutral at this time, although it has been black alkaline in the past, and for that reason has not been an aid in reclaiming the black alkali soil.

11. Arizona has unlimited supplies of high grade gypsum, beds of which occur near the University Farm.

12. Crop histories and maps are given for the experiment plots from 1915 to 1919 when the first systematic application of gypsum to the tract was made.

13. Feterita in 1915 is shown to have had a very detrimental effect on the barley crop the following winter, but the soil recovered its normal fertility with the corn crop in 1916.

14. In 1919 the lands were sampled and treated with gypsum according to analysis, each 50 feet of border receiving from 500 to 3,000 pounds of gypsum. The reclamation was unsatisfactory.

15. In 1920, Land 35 received an additional 10 tons of gypsum distributed according to analysis; Land 36, 10 tons of gypsum and 20 tons of manure; Land 37, the same treatment plus leaching for 12 hours; Land 38, 20 tons of manure. Good barley was produced on all the lands, except Land 38.

16. The quality of the gypsum used in 1920 was questionable; therefore, the treatment was duplicated in 1921. Land 38 produced more barley and wheat than did Land 35. The combination of gypsum and manure produced heavier crops than the sum of the two used singly. * Leaching gave no special advantage with the winter crops. The crops on the combined treatment plots were considerably heavier than the average for the same crops on the Salt River Valley Farm at Mesa.

17. The succeeding corn crop showed the effect of manure on alkali to be very short-lived.

18. Analyses of soil samples taken after the last crop had been removed do not show deep penetration of the gypsum, but crops on the land indicate that if an excess of gypsum is kept in the surface foot, a considerable concentration of black alkali will be tolerated in the subsoil.

19. Chemicals other than gypsum, several of which are or can be made as by-products of the mining and smelting industries, undoubtedly may be used with equally good effect.

20. While chemical treatment may prove too expensive for reclaiming large areas of strongly alkaline soil, small areas on otherwise valuable farms will justify relatively heavy expenditures.