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INFLUENCE OF COLORADO RIVER SILT ON SOME PROPERTIES OF YUMA MESA SANDY SOIL

By

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INFLUENCE OF COLORADO RIVER SILT ON SOME PROPERTIES OF YUMA MESA SANDY SOIL

BY W. T. McGEORGE

INTRODUCTION

The rivers which are the source of irrigation water in the Southwest carry large quantities of silt particularly during flood time. On the lands where the soil already contains all the clay fraction it can structurally assimilate, silty irrigation water is a menace to the maintenance of a soil structure suited to irrigation agriculture. Also it is a further menace because of its deposition in reservoirs and canal lines from which its removal is costly. On the other hand, silt is the creator of much of the agricultural wealth of the alluvial valleys of Arizona, for where it has been properly incorporated in the soil mass it has structurally improved sandy areas and supplied many thousand tons of calcareous, nitrogenous, phosphatic, and potash bearing materials. The color and character of the silt varies with the watershed and formation from which it is derived and consists of finely divided or pulverized rock, eroded soil, and organic debris.

Since the construction of storage reservoirs, notably the Roosevelt, Coolidge, and Boulder dams, the silt load of Arizona rivers has been notably reduced. Likewise the farm problems connected with the handling of silt have been reduced, all of which is a distinct advantage to farmers cropping most of the valley lands that cannot, structurally, assimilate any more silt. Since silt may improve sandy lands both chemically and physically, a study of this phase of the problem as it concerns the mesa lands near Yuma, Arizona, has been made.

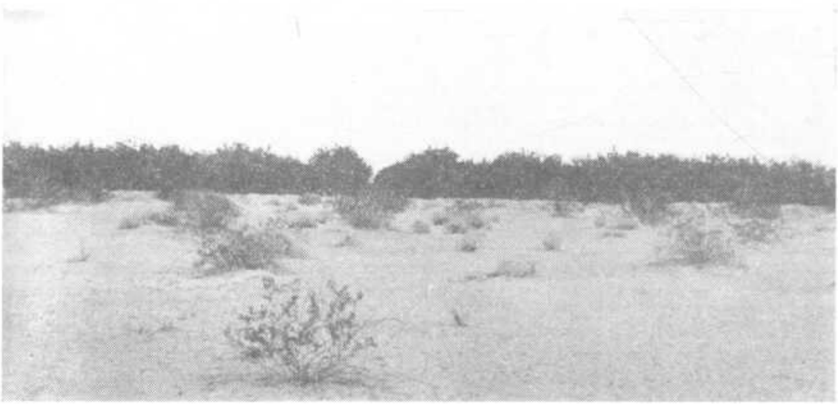

Plate I.—Yuma mesa land showing grapefruit orchard on Unit B in the background.

This large area of mesa land, for which water is being provided by the Yuma-Gila project, consists of approximately 150,000 acres which are in large part sandy soil classified as Superstition sand. Physically it analyzes approximately 90 per cent sand (0.05 to 1.0 mm.), has a moisture equivalent of only 4 to 5 per cent, and contains practically no organic matter. Obviously such a soil will be greatly improved by properly incorporating river silt. In fact the success or failure of the project may depend upon an improvement in soil structure which the silt would impart to this type of soil.

REVIEW OF LITERATURE

When the Arizona Agricultural Experiment Station was established in 1890, the heavy silt load carried by irrigation water was recognized as a problem calling for immediate attention. Information obtained by Forbes (2, 3) in these early studies is of interest to the present study of the Yuma mesa problem and is therefore reproduced in part. He made silt load determinations regularly over a period of 1 year (1899-1900) for the three largest rivers. The minimum and maximum as well as average loads for the year are given in Table 1. There were no large storage reservoirs on the rivers at that time.

TABLE 1.—SILT LOAD CARRIED BY ARIZONA RIVERS, 1899-1900.

Location	Mm. silt per acre-ft. water (tons)	Max. silt per acre-ft. water (tons)	Av. silt per acre-ft. water (tons)
Gila at Florence	0.11	128.03	19.23
Salt at McDowell	0.05	12.95	1.20
Colorado at Yuma	1.14	44.42	9.62

On the basis of 4 acre-feet of water per year as an average water requirement, the following calculations were made by Forbes.

TABLE 2.—SILT PER 4 ACRE-FEET OF WATER ON BASIS OF DATA GIVEN IN TABLE 1.

Location	Tons sediment in 4 acre-feet water	Inches sediment deposited on soil
Gila at Florence	76.94	0.46
Salt at McDowell	4.79	0.03
Colorado at Yuma	38 49	0.23

Of course the entire silt load of a river is not carried to the land, because it deposits, in part, in the reservoirs and canals. Furthermore that which reaches the field is not evenly distributed for it is deposited in largest part at the head of the irrigation run, in next largest part at the end of the run, and least in the middle. The above data are introduced to show the magnitude of the silt load problem. If the silt is allowed to accumulate in successive layers to form a blanket on the surface of the land, serious struc-

Plate II.—View of soil and plant cover on Yuma mesa land.

tural problems will ultimately arise. It should be regularly incorporated as thoroughly as possible within the entire mass of soil by tillage.

In December, 1935, a preliminary survey of the Yuma mesa was made[1] and soil samples taken from virgin areas, mesa land that had been irrigated with silty water, and from Datelan, near Tacna, where land similar to the Yuma mesa was being cropped. The mechanical analyses of some of the soil samples taken at that time are given in Table 3. Numbers 1 and 2 are samples of virgin soil; number 3 had been irrigated with silty Colorado River water since 1927, 8 years; number 4 since 1932, 3 years; number 5 since 1921, 14 years (the subsoil to number 5 is given as number 6). Numbers 7 and 8 are cultivated and virgin sandy soil from Datelan. Three years' irrigation on soil number 4 had reduced the percentage of sand to 86.3 and increased the clay fraction to 9.8 in the surface

TABLE 3.—MECHANICAL ANALYSES OF SOILS FROM YUMA MESA.

Description	Depth of sample (inches)	Per cent sand	Per cent silt	Per cent clay	Moisture equiv.
1. Virgin	0—24	94.6	2.0	3.4	4.12
2. Virgin	0—24	89.6	4.6	5.8	4.53
3. 1927	0— 8	85.8	3.8	10.4	7.16
4. 1932	0 — 8	86.3	3.9	9.8	6.86
5 1921	0 — 8	65.8	10.3	23 9	16.83
6. 1921	8—24	90.8	4.8	4.4	5.36
7. Datelan, cult.	0—24	86.7	1.1	12.2	9.51
8. Datelan, virgin	0—24	87.6	4.6	7.7	5.83

[1]An unpublished report by R. S. Hawkins, H. V. Smith, and A. F. Kinnison.

8 inches. Eight years' irrigation on sample number 3 had reduced the percentage of sand to 85.8 and increased the clay fraction to 10.4 in the surface 8 inches. Fourteen years' irrigation on sample number 5 had reduced the sand to 65.8 per cent and increased the clay fraction to 23.9 and silt to 10.3. The analysis of sample number 6, which is the subsoil to number 5, shows that none of the suspended silt in the water had penetrated the sand below 8 inches.

In addition to the structural soil problems involved in handling river silt on the land, there is also the fertilizer value of the material, and this too was studied by Forbes (2, 3) as shown in Table 4.

TABLE 4.—POUNDS POTASH, PHOSPHORIC ACID, AND NITROGEN IN SEDIMENTS, (MINIMUM, MAXIMUM, AND AVERAGE PER ACRE-FOOT OF WATER).

Gila River, Nov. 28, 1899 to Nov. 5, 1900					
Potash (K_2O)	From	2.7	to	2,621.8	(av. 214.3)
Phosphoric acid (P_2O_5)	From	1.8	to	352.1	(av. 36.9)
Nitrogen (N)	From	0.98	to	172.3	(av. 28.1)
Salt River, Aug. 1, 1899 to Aug. 4, 1900					
Potash (K_2O)	From	4.1	to	267.4	(av. 18)
Phosphoric acid (P_2O_5)	From	1.5	to	73.1	(av. 6.6)
Nitrogen (N)	From	0.16	to	69.4	(av. 5.5)
Colorado River, Jan. 10, 1900 to Jan. 24, 1901					
Potash (K_2O)	From	14.7	to	444.6	(av. 113,1)
Phosphoric acid (P_2O_5)	From	2.3	to	43.6	(av. 10.0)
Nitrogen (N)	From	0.0	to	38.3	(av. 4.8)

These data illustrate the wide fluctuation in chemical composition and fertilizing value of the silt with season, rainfall, and watershed. The fertilizing value depends largely upon whether the silt conies from barren desert waste or forested lands. At the time these data were obtained, it is evident that the Gila River was carrying the most valuable silt. On the basis of nitrogen at 12 cents per pound, phosphoric acid (P_2O_5) at 4 cents per pound, and potash (K_2O) at 5 cents per pound the fertilizer value per acre-foot of Colorado River water, as calculated from Forbes's data, would be about $6. At the rate of 5 acre-feet per year this would be $30 per year.

The silt load and its fertilizing value vary widely during the year. During the period, September to March, the Colorado River is usually low. During this time the silt load is low but the salt content is high, and the water carries an appreciable amount of gypsum in solution. In May and June the floods start from melting snow on the watersheds, and this produces an increase in the silt load but a decrease in the salt content of the water. About the time the floods from melting snow are completed, the summer rains in northern Arizona and New Mexico start with periodic floods. These bring about a further increase in silt load and further reduction in salt content. The silt load reaches its maximum during this period. The water also often shows phenolphthalein alkalinity during this period, and this alkalinity tends to produce a greater dispersion of silt and therefore a greater silt load (1).

Obviously, on this basis, there will be a wide variation in the fertilizer value of the silt during these periods, and this is confirmed by further data obtained by Forbes and given in Table 5.

TABLE 5.—POUNDS P_2O_5, K_2O, N IN COLORADO RIVER SEDIMENTS AND WATER, JAN. 10, 1900, TO JAN. 24, 1901,

Date	Phosphoric acid (P_2O_5)	Potash (K_2O)	Nitrogen (N)
1-10 to 3-26	2.26	16.34	1.03
3-27 to 4-30	5.99	25.05	2.87
5-1 to 7-11	10.89	59.99	....
5-1 to 6-30	....	....	4.92
7-12 to 9-13	3.27	14.70	....
7-1 to 8-21	....	....	1 64
9-14 to 10-13	43.56	444.60	....
8-22 to 9-26	....	....	3.29
10-14 to 12-1	18.51	134.75	....
9-27 to 11-14	....	....	17 39
12-2 to 1-24	4.00	288.6	....
12-15 to 1-24	....	....	3.98

Further information has been made available for the Colorado River at Yuma by Fortier and Blaney (4). They present quantitative silt load data determined twice weekly over a period extending from 1910 to 1925 inclusive by the Bureau of Reclamation. These data are shown graphically in Figure 1 and are in close agreement with Forbes's data on seasonal variation in silt load of the Colorado River at Yuma.

The foregoing references show that the alluvial silts which have been spread over the valley floors of southern Arizona have contributed much to their present potential fertility and structurally improved many of the sandy soil types. Since a large part of the silt in the Colorado River is now being deposited behind Boulder, Parker, and Imperial dams and further provision has been made for silt removal by the installation of desilting structures at Parker Dam, this should be of great benefit to the lands in the Yuma Valley. The ultimate success of desilted water on the Yuma mesa is however another question. The present investigation was made to obtain information on this.

EXPERIMENTAL

OUTLINE OF EXPERIMENTS

While it is recognized that structural studies are best conducted on the soil as it actually exists undisturbed in the field, it is obvious that such a plan was not feasible in this case. In view of this and also because soil structure cannot be quantitatively expressed, the studies were conducted in the laboratory by determin-

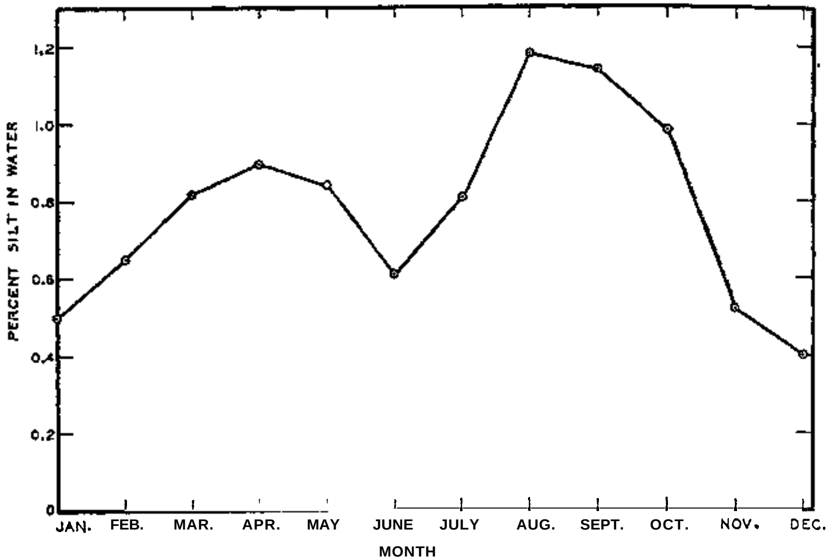

Figure 1.—Per cent silt in Colorado River water by months (average of 15 year record).

ing certain physical constants for various prepared silt and sand mixtures. These were settling volume, apparent specific gravity, pore space, water-holding capacity, moisture equivalent, percolation rate, and rate of capillary water movement. The fertilizer value of the silt was studied by employing the Neubauer method of measuring plant food availability in soil.

Mixtures of air-dry sand and river silt were prepared in the following proportions: 100 sand, 0 silt; 90 sand, 10 silt; 80 sand, 20 silt; 70 sand, 30 silt; 60 sand, 40 silt; 50 sand, 50 silt; 40 sand, 60 silt; 30 sand, 70 silt; 20 sand, 80 silt; 10 sand, 90 silt; 0 sand, 100 silt. These were analyzed to demonstrate the desirable and undesirable properties of the various proportions of each.

The mechanical composition of the silt load carried by a river depends upon the velocity and other factors. In view of this the silt is classified as bed silt, which contains appreciable fine sand and coarse silt particles, or suspended silt, which is in major part fine silt and clay. For the experiments presented in this bulletin Superstition sand was obtained from the Yuma mesa. Bed silt and suspended silt were obtained from a canal at Yuma. The mechanical analyses and partial chemical analyses of these materials are given in Table 6. The mechanical analyses show the composition of river silt—namely, that it is not true silt but a variable mixture of different sized particles varying from colloidal clay to fine sand depending upon such factors as rate of stream flow, pH of the water and silt, salt content of the water, and possibly other factors.

TABLE 6.—PARTIAL CHEMICAL AND MECHANICAL ANALYSES OF SAND AND SILTS.

	Sand	Silt No. 1 bed silt	Silt No. 2 suspended silt
Per cent sand (0.05 to 1 mm.)	88	60	27
Per cent silt (0.005 to 0.05 mm.)	6	27	22
Per cent clay (0.000 to 0,005 mm.)	6	13	51
Specific gravity, real	2.61	2 57	2 50
Calcium carbonate, per cent $CaCO_3$	3.62	4.46	7.48
Exchange capacity, M.E. per 100 gm.	4.6	9.2	26.0
Avail. phosphate, ppm. PO_4 in soil	2.0	9 0	2 5
Avail. potassium, ppm K in soil	24.0	198 0	99 0
pH, 1:5 soil-water ratio	8 45	8 10	8 20

Mechanically a soil may be classified structurally or texturally. The textural composition is determined by the particle sizes, such as sand, silt, and clay without regard to their arrangement or distribution. The structural composition of the soil concerns the arrangement or grouping of the different sized particles. Structure and texture together determine the mechanical properties of the soil and particularly the movement of air and water within the soil mass. In a type like the Superstition sand of the Yuma mesa, structure and texture are essentially the same. Structural changes are caused by variable fitting of the finer soil particles, notably the clay and silt fractions, into the spaces between the large sand particles. Superstition sand, having a single grain structure of sandy particles and little or no colloidal silt or clay, possesses a structure which is practically unalterable. With such a single grain structure the rapid movement of water requires frequent and excessive irrigation to keep a crop supplied with water. Obviously then this soil can only be structurally improved by changing the texture. That is by incorporating fine soil particles which fortunately are available in silt laden water.

Since irrigation and fertilization economies are going to be a big factor in the cropping of the Yuma mesa lands, this investigation was designed to study river silt as a means of effecting such economies. Water economy can be accomplished by changing the texture of the soil—that is, by incorporating silt or organic matter. This will at the same time change the soil structure by increasing the amount of pore space yet reducing the size of individual pores.

SETTLING VOLUME, APPARENT SPECIFIC GRAVITY, AND PORE SPACE

As already mentioned structure is a soil property which can better be described than measured. Among the physical constants used to demonstrate changes in structure, the apparent specific gravity or volume weight is often employed because it indicates the volume of pore space in the soil. When this pore space is compared with the texture much evidence regarding the structure can be obtained.

There is not a great deal of variation in the real specific gravity of the mineral particles that make up a soil. Therefore in semi-arid soils, which are practically free of organic matter, this value is reasonably constant. On the other hand the apparent specific gravity or volume weight, which includes the pore space, is widely variable depending both on structure and texture. The greater the pore space the lighter the volume weight. The minimum and maximum limits for clay are 1.1 to 1.3, while for sand they are 1.5 to 1.8. Thus so-called heavy soils are only heavy in the sense that they are heavy to work.

There is an appreciable error in the volume weight and pore space determinations in soils depending in part upon whether they are made on disturbed soils in the laboratory or on samples taken in the field and representing the unaltered field structure. While the latter method is preferable, it was necessary to use laboratory rather than field methods in this study. Settling volume was determined by adding 25 grams air-dry soil to 30 ml. of water, shaking vigorously, and allowing the whole to settle to constant volume, 48 hours. The volume weight and pore space determinations were made on this group of sand-silt mixtures by calculation from the weight of air-dry soil and weight of water displaced in the settling volume determination. In making the pore space calculations there is an additional error in the procedure in that the large sand particles have a more rapid settling rate, and only a part of the silt will settle within the larger pores. The rest will settle upon the surface of the column. This error is however reduced to a minimum by working with a small volume of water in proportion to soil as was done in this experiment.

The data for settling volume of 25 grams of air-dry soil, apparent specific gravity, and pore space are given in Table 7 and for sand-silt number 2 in Figure 2. Pore space was calculated by dividing

TABLE 7.—SETTLING VOLUME, APPARENT SPECIFIC GRAVITY, AND PORE SPACE IN SAND-SILT MIXTURES.

Sample no.	Sand	Silt	Ml. set. volume sand-silt No. 1	Ml. set. volume sand-silt No. 2	App. sp. gravity sand-silt No. 2	Pore space sand-silt No. 2
1	100	0	17.5	18.0	1.72	34.1
2	90	10	19.0	20.5	1.66	36.1
3	80	20	19.2	21.5	1.61	37.8
4	70	30	20.5	24.5	1.66	35.7
5	60	40	20.5	24.5	1.61	37.4
6	50	50	20.5	26.0	1.56	38.9
7	40	60	21.0	28.0	1.56	38.8
8	30	70	22.0	29.0	1.51	40.5
9	20	80	22.5	29.5	1.47	41.8
10	10	90	22.5	30.0	1.42	43.6
11	0	100	23.0	31.0	1.37	45.2

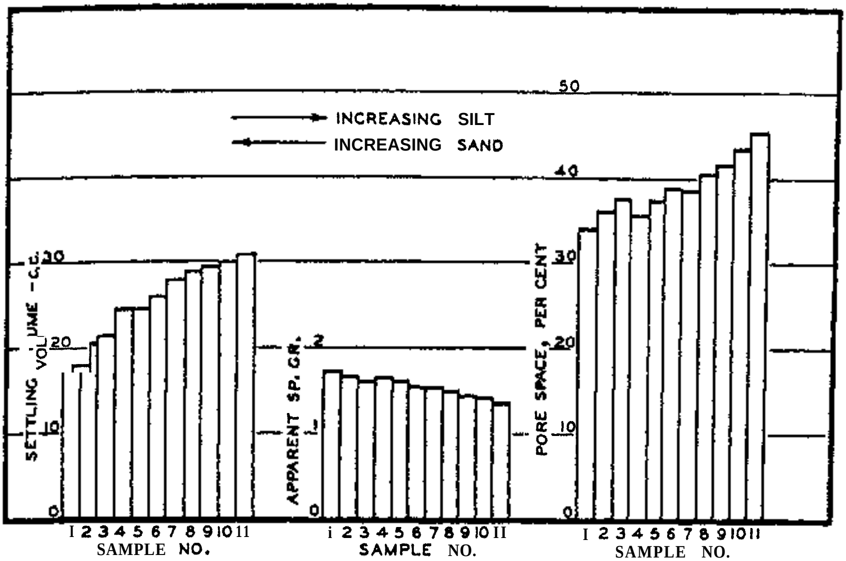

Figure 2.—Settling volume of 25 grams of air-dry soil, apparent specific gravity, and per cent pore space in sand-silt mixtures.

the difference between the real and apparent specific gravities by the real specific gravity.

These data show an increase in settling volume, a decrease in apparent specific gravity, and an increase in pore space with increase in ratio of silt to sand in the mixtures. This increase in pore space is accompanied by an increase in number but decrease in size of individual pores. This should reduce the rate of water movement and increase the water-holding capacity of the soil. That is, there should be a lower rate of water penetration and an increase in length of intervals between irrigations. This is further demonstrated by moisture equivalent and water-holding capacity determinations.

MOISTURE EQUIVALENT AND WATER-HOLDING CAPACITY

The moisture equivalent (M.E.) is an arbitrary yet extremely useful moisture value established by Briggs and McLane, for all soils are considered equally wet at this point even though the percentage of moisture in them is different. It is determined by placing the air-dry soil in flat screen-bottomed square cups in which it is allowed to saturate with water by capillarity. The cups are then whirled in a special type centrifuge at a force 1,000 times gravity for ½ hour. The amount of water held by the soil against this force is known as the moisture equivalent and is determined by weighing the soil after removal from the centrifuge and after drying in the oven. The moisture equivalent is also a measure of soil texture.

The water-holding capacity was determined by the Hilgard method in which a layer of soil 1 centimeter deep is placed in a special screen-bottom cup, saturated with water by capillarity, drained by placing in a saturated atmosphere for 24 hours, and then determining the water in the regular manner by drying in the oven.

The data are given in Figure 3. In the mixture of sand and number 2 silt the moisture equivalent was more than doubled by the incorporation of 20 parts silt with 80 parts of sand. A moisture equivalent of 10 is a reasonable value for good semiarid soils which are practically free of organic matter. The water-holding capacity is also greatly improved by the incorporation of silt.

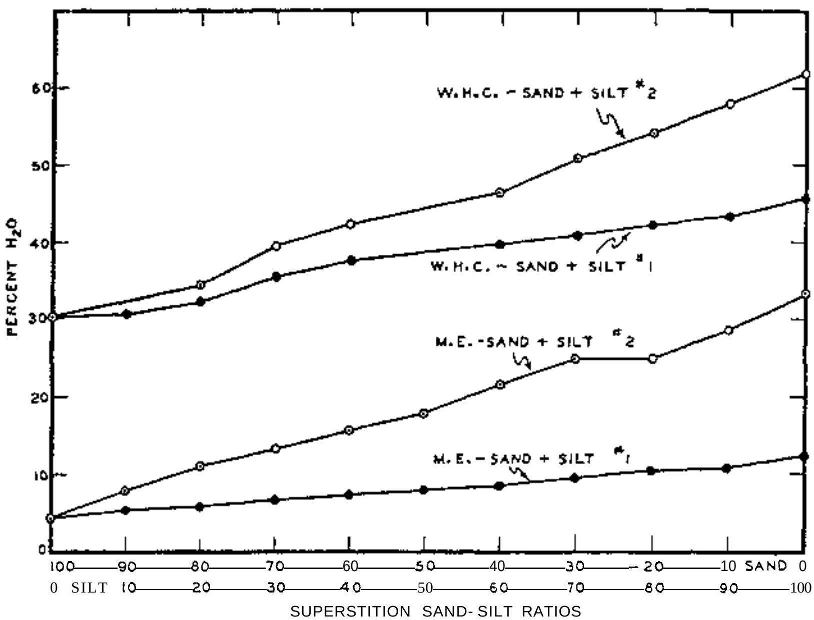

Figure 3.—Per cent moisture equivalent and water-holding capacity in sand-silt mixtures.

RATE OF PERCOLATION AND CAPILLARITY

Water movement and retention within the soil mass are two extremely important phases of the moisture problem as related to irrigated soils, for moisture is by far the greatest growth limiting factor in semiarid regions. Since the capillary water is the primary source of water for plants, this form of soil moisture is of special interest. The rapid rate of capillary movement in Superstition sand is probably the principal soil problem involved in the economic husbandry of this land. Capillary movement depends upon the resistance offered by the pore spaces. It depends more upon the size of the individual pores than on the total amount of pore space. Thus a sand will drain more readily than a clay, on a dry basis will contain less water and will lose water more quickly than a clay. Ascent of water is most rapid in sand but will also reach its maximum height more quickly. It is slower for clay, as clay offers greatest resistance to movement of water, but in the end capillary water will reach a greater height. Using a method similar to that employed here, Hilgard[2] determined the maximum height to which capillary water was drawn in a soil from the lower Gila River district. The soil contained 72 per cent sand, 21 per cent silt, and 3 per cent clay, and the water rose to a height of 47 inches in 125 days beyond which there was no further rise. This is compared with a soil containing 89 per cent sand in which the water rose to only 17 inches and was complete in 6 days.

Incorporating silt with the sand, from silt-laden water, is the most feasible way of reducing the excessive rate of capillary water movement in the Yuma mesa lands. This will increase the total pore space, increase the resistance to flow of water, and also the water-holding capacity of the soil. This was proved in part by the water-holding capacity studies in Figure 3 and is further demonstrated by the data give in Table 8 and Figure 4.

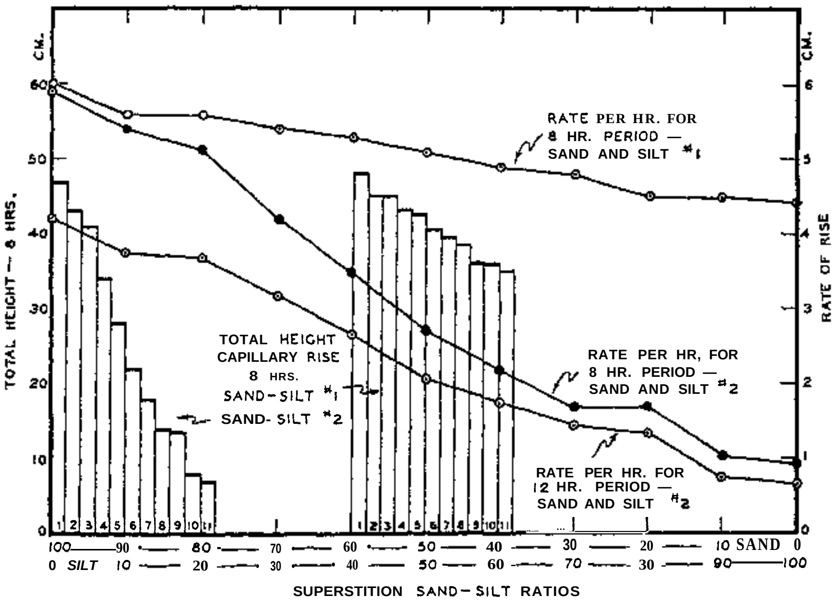

Figure 4.—Capillary water movement in sand-silt mixtures. Total height and rate per hour for 8 hours.

[2] E. W. Hilgard, *Soils*, The Macmillan Co., p. 205.

Pore space represents usually 25 to 50 per cent of the volume of the soil. The optimum condition for plant growth exists when about 50 per cent of the pore space is filled with water. This leaves about 50 per cent of the pore space filled with air to support root respiration. In a sandy type such as the Superstition sand, the pore spaces are so large that the moisture content of the pore space is lowered and the air content increased beyond the optimum. In a heavy clay soil such as is represented by river silt, just the opposite condition exists at approximate field moisture capacity. The advantage of using enough silty river water to increase the silt content of Superstition sand to 10 or even 20 per cent is quite obvious.

Percolation rate was determined by percolating tap water, keeping the head of water constant, through a column of soil 7.5 inches long and 1.25 inches in diameter. The soils were placed in the tubes in the air-dry condition. Tap water, which contains about 500 parts per million soluble salt, was used in preference to distilled water, because it more closely represents irrigation water. Percolation was continued for 8 hours after the soils had become completely wetted, and the data given in Table 8 represent the average hourly drainage from the soil columns for the 8 hour period.

Capillary rate of water movement was determined by packing a 50 centimeter column of soil in a 1 inch glass tube and setting in a reservoir of tap water. The rate of water rise is given in Table 8 as rate per hour over an 8 hour period, also in Figure 4 the rate is shown over a 12 as well as an 8 hour period.

TABLE 8.—PERCOLATION RATE AND CAPILLARY RATE OF SAND-SILT MIXTURES.

Soil no.	Sand	Silt	Percolation rate (ml./hr.)		Capillary rate (cm./hr.)	
			Sand-silt 1	Sand-silt 2	Sand-silt 1	Sand-silt 2
1	100	0	130	123	6.0	6.0
2	90	10	52	33	5.6	5.4
3	80	20	32	18	5.6	5.1
4	70	30	30	12	5.4	4.2
5	60	40	27	5.5	5.3	3.5
6	50	50	23	3.0	5.1	2.7
7	40	60	18	2.4	4.9	2.2
8	30	70	16	2.0	4.8	1.7
9	20	80	13	1.6	4.5	1.7
10	10	90	10	1.9	4.5	1.0
11	0	100	7	1.3	4.4	0.9

The importance of silt laden water for the Yuma mesa is clearly demonstrated in this experiment. Incorporation of 10 parts of silt with 90 parts Superstition sand has reduced the rate of percolation (increased the resistance to water flow) about 75 per cent for sand-silt number 2. Likewise the capillary rise in water has been reduced in rate. The data show that notable savings in the cost of irrigating the Yuma mesa lands can be obtained by the use of silt laden water for irrigation if the silt is incorporated with the soil by tillage.

NEUBAUER STUDIES

Judging from the river silt analyses made by Forbes (2, 3) as well as analyses made since that time, there should be an appreciable improvement in the fertility of sandy land because of the potash, phosphate, and nitrogen present in the material. As a means of studying this phase of the silt problem, as it concerns the Yuma mesa, the Neubauer method of measuring plant food availability in soils was employed. In this method the available plant food is measured by using rye plants for extraction rather than acid or alkaline solutions, water, or other solvents.

In a chemical method developed in this laboratory the available potassium and phosphate are determined by their solubility in carbonic acid, and the values thus obtained for the two silts and the Superstition sand are given in Table 6, All are high in available potassium, as determined by this method, which explains why it has not been found necessary to use potash fertilizers on the alluvial valleys of southern Arizona. Available phosphate is low in the sand and in silt number 2 but high in silt number 1 which is the bed silt. In view of the fact that calcium carbonate reduces the solubility of phosphate, it is probable that the higher calcium carbonate content of silt number 2, the suspended silt, as well as its finer state of division, is the cause of this low solubility in carbonic acid.

The Neubauer method of measuring available postassium and phosphate in soils has been extensively employed on Arizona soils and is believed to be a reasonably accurate yard stick. Briefly this method consists in planting 100 rye seeds in 100 grams of air-dry soil, harvesting the plants at the age of 15 to 18 days and determining, by analysis of the plants, the amount of potassium, phosphate, or calcium removed. A comparison is made with 100 rye plants grown for the same period in silica sand. The difference between the two sets of plants represents the amount (milligrams) of the different elements extracted by the plant roots from 100 grams of soil. While the original method suggests the use of rye, it is possible to use other plants and by following the same procedure extend the value of the method. The limiting factor in the choice of other plants is the uniformity in size and chemical composition of the seed, for wide variations will reduce the accuracy or reproducibility of the method. Experiments have shown that Sacramento barley is sufficiently uniform, and it has therefore been used in this study as a means of checking the availability as measured by rye plants.

Potassium.—The potassium (K) values for the sand-silt mixtures are given in Figures 5 and 6 as milligrams K per 100 plants. By estimating from the horizontal line drawn through the potassium content of the plants grown in silica sand, actual Neubauer values may be obtained. These data show a rapidly increasing

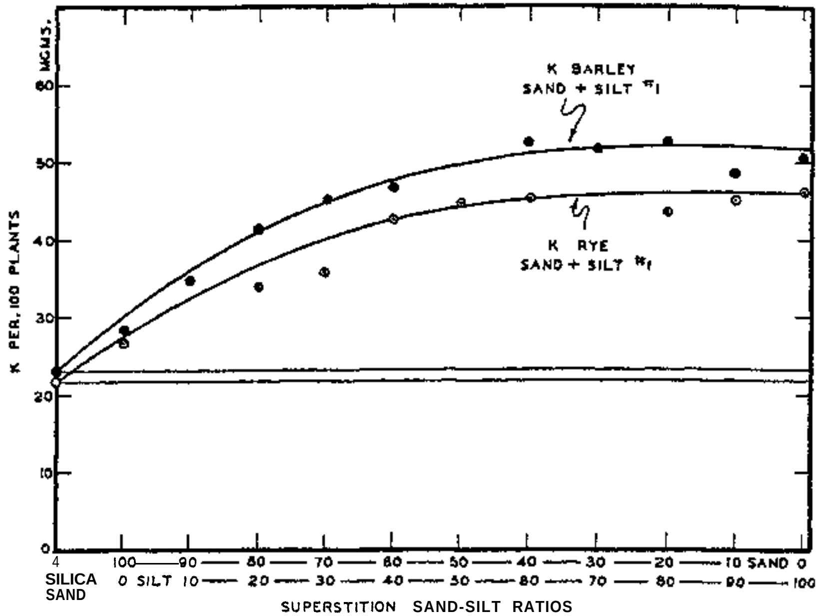

Figure 5.—Milligrams K removed from 100 grams sand-silt number 1 mixtures by 100 rye and 100 barley plants.

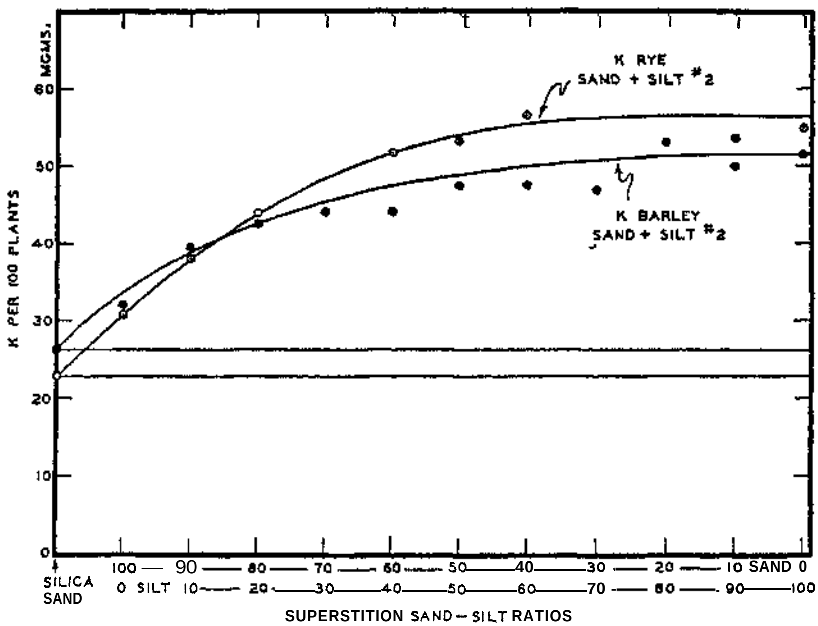

Figure 6.—Milligrams K removed from 100 grams sand-silt number 2 mixtures by 100 rye and 100 barley plants.

availability of potassium with increase in ratio of silt to sand in the mixtures up to 50 parts silt and 50 parts Superstition sand. Above this ratio the amount of potassium per 100 plants, or amount of potassium absorbed by 100 plants from 100 grams of soil, is practically a constant. Plants will usually absorb more potassium than actually needed when an excess of available potassium is present in the soil, a condition often referred to as luxury consumption. These experiments show therefore that there is no luxury consumption from sand-silt mixtures above equal parts silt and sand and that an adequate absorption of potassium was obtained well below this ratio. Thornton (5) has suggested a limit value of 8.3 potassium (K) for American soils. That is, K values below 8.3 for soils indicate a deficiency of available potassium, and where such low values are found potassium fertilizers are recommended, while soils with values greater than 8.3 should not require potassium fertilization for most crops. The K values for the Superstition sand are very close to the limit value of 8.3, but with as little as 10 parts silt to 90 parts sand the K value is raised well above this limit value. It is clearly evident from these data that the use of silty Colorado River water for irrigation of the Yuma mesa will supply sufficient potassium for good crop growth and will indefinitely postpone the time when potash fertilization will become necessary on these lands. This end may be attained by incorporation of as little as 20 per cent silt or possibly less in 12 to 18 inches of Superstition sand.

It is of interest that the K values for barley and rye are closely equal and that the curves follow the same general directional trend. The only difference is in the greater absorption of potassium from the heavier silt by the rye plants, while the absorption from the lighter bed silt is greater for the barley.

Phosphate.—The phosphate (PO_4) values are given in Figures 7 and 8 as milligrams PO_4 per 100 plants and again as Neubauer values by estimation from the horizontal line drawn through the PO_4 content of the plants grown in silica sand. The data show considerable difference between the availability of phosphate and potassium in both silts when mixed with the Superstition sand. The constant PO_4 values are reached at a lower silt-sand ratio than the constant K values. In fact there is only a small increase from silt incorporation which will, however, appear of greater magnitude if one recognizes the small phosphate requirement of plants as compared with potassium. The amount of PO_4 absorbed by 100 plants from 100 grams of soil is practically constant above a ratio of 20 to 30 parts of silt to 70 to 80 parts of sand. The minimum or limit value for PO_4, suggested by Thornton (5) from his work on American soils, is 5.3 PO_4 or 4.0 P_2O_5. On this basis the Superstition sand is deficient in available phosphate, and this is confirmed by fertilizer field tests with phosphates on the Yuma mesa. By incorporating 10 parts silt with 90 parts sandy soil the Neubauer value was increased to approximately 5.3, which is the limit value. There is a further increase for the ratio of 20 parts

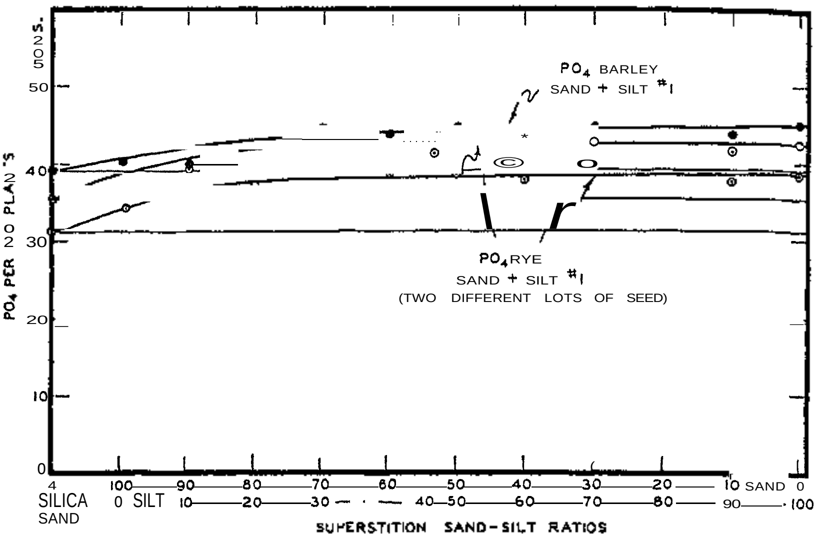

Figure 7.—Milligrams PO_4 removed from 100 grams sand-silt number 1 mixtures by 100 rye and 100 barley plants.

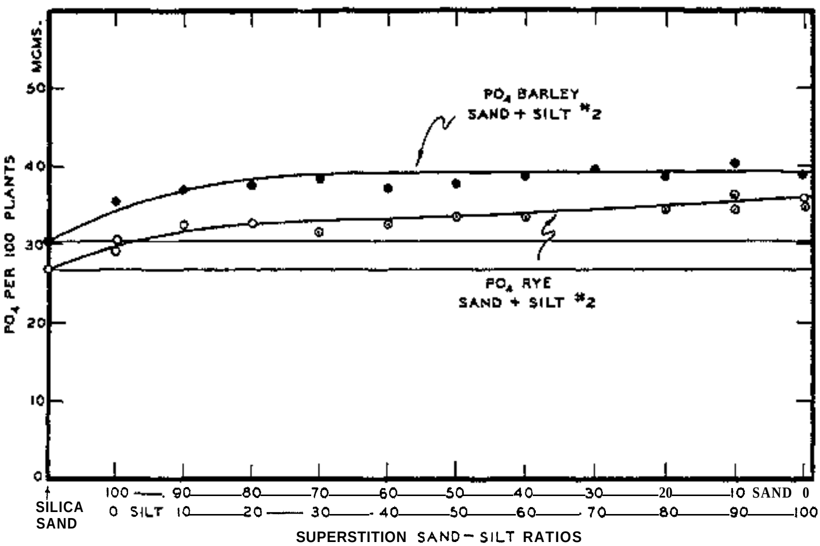

Figure 8.—Milligrams PCX removed from 100 grams sand-silt number 2 mixtures by 100 rye and 100 barley plants.

silt to 80 parts sandy soil. Above this the values are closely constant. This indicates that so far as phosphate availability is concerned an incorporation of 20 per cent silt in Superstition sand will produce conditions of phosphate availability which are closely optimum.

There are several factors involved in the lesser availability of phosphate in these sand-silt mixtures as compared with potassium. For one thing plants require more potassium than phosphate for normal growth. Also the calcium carbonate content, the pH, and the fineness of division of the silt and clay particles all reduce phosphate availability and antagonize phosphate absorption by roots. Obviously then as the silt increases above a certain level there is an increase in all three of these depressing factors. The process of potassium absorption by roots is in large part an exchange reaction between the roots and the exchange complex of the soil or the soil solution and is less affected by the factors which interfere with phosphate absorption. The process of phosphate absorption by roots is one which demands a pH value of 7.6 or less in the root-soil contact film. Thus in heavy soils and in the presence of an excess of finely divided calcareous silt, such as in these experiments, root respiration will be reduced, and active root respiration is a nutritional essential for the maximum growth of plants in alkaline-calcareous soils. This applies especially to phosphate ion absorption by roots but is also true for other elements the solubility of which is reduced by the presence of calcium carbonate and high soil pH values.

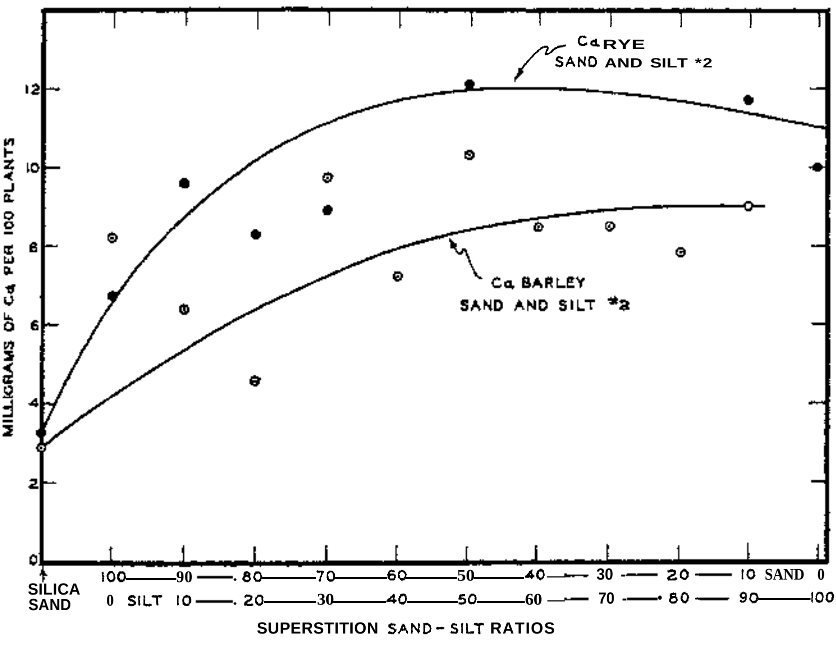

Figure 9.—Milligrams Ca removed from 100 grams sand-silt number 2 mixtures by 100 rye and 100 barley plants.

It is of interest that the directional trend of the phosphate curve for barley is similar to that of rye and that barley is a stronger phosphate feeder than rye or has a greater phosphate requirement.

Calcium.—While the original Neubauer method has not been suggested as a measure of calcium availability in soils, it has been used to a limited extent for that purpose in this laboratory. The calcium values for these sand-silt mixtures are given in Figure 9. The separate calcium determinations in this experiment show such wide variations that the curves in this figure are only an approximation. They do, however, show a definite directional trend—namely, an increase in available calcium by silt incorporation. It is not possible to comment at length on the significance of these calcium data. An investigation of calcium availability and absorption of calcium by plants in alkaline-calcareous soils is now under way as a separate project.

SUMMARY

Due to the open single grain structure of Superstition sandy soil type of the Yuma mesa, excessive amounts of irrigation water are required to support maximum crop growth. The low water-holding capacity and the rapid rate at which water percolates through this soil make frequent irrigation necessary especially during the summer months. There are several ways in which the soil structure can be changed to improve these conditions—that is, to increase the water-holding capacity and resistance to flow of water. The most important are incorporation of river silt, organic matter, or a combination of the two.

Data presented in this bulletin show that both structurally and texturally Superstition sand can be improved by incorporating Colorado River silt. The investigation suggests that some provision should be made to supply silty water to these mesa lands for irrigation and that it should be supplied over a long enough period to add 15 to 20 per cent to about an 18 inch depth of sandy soil. This proportion of silt to sand will impart a reasonable water-holding capacity and retention of irrigation water. It will also materially increase the level of available phosphate and potash.

In view of the extension of the Gila Irrigation Project into the lower Gila River district where some sandy mesa lands exist, the same improvement in soil structure from silty water can be attained.

CONCLUSIONS

1. Settling volume, ~~apparent specific gravity~~, pore space, moisture equivalent, and water-holding capacity of Superstition sand are all increased by incorporating Colorado River silt.

2. Percolation rate and rate of capillary water movement are reduced by incorporating silt.

3. A sizable supply of available potassium, calcium, and phosphate is added to these sandy areas by incorporation of river silt.

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