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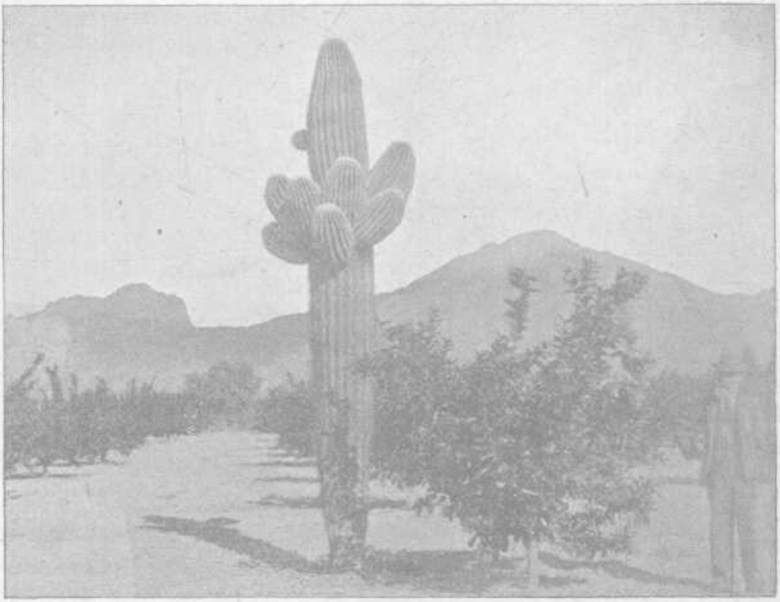

Salt River Valley,—past and present. Young orange and lemon trees on the site of a cactus desert.

BULLETIN NO. 28.

Salt River Valley Soils.

BY

ROBERT H. FORBES.

Tucson, Arizona, March, 1898.

Arizona Agricultural Experiment Station.

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EXPERIMENT STATION,

Tucson, Arizona.

SALT RIVER VALLEY SOILS.

By Robert H. Forbes.

GENERAL REMARKS.

The seemingly miraculous transformation of our western deserts into fruitful orchards and green fields is, in an eminent degree, brought about by the magic of hard and thoughtful labor. Nature must be won over to the cause of agriculture by the expensive process of irrigation, and unfavorable conditions of soil and climate must be studied out and overcome by those, who, for the most part, come from humid regions where other methods of farming are practiced.

The western farmer, therefore, confronted by new agricultural problems, has need of wide scientific information, as well as of means and ingenuity to apply it to the work in hand. It is the object of this writing to present the results of a study of the soils of Salt River Valley, point out their merits and defects from an agricultural point of view, and make such suggestions as may be of practical value in this connection.

Salt River Valley, popularly speaking, consists of the irrigated portion of Maricopa County, lying under ditches mainly supplied by the Salt River. At the present time this is the most important agricultural district in Arizona, and contains about 457 square miles of good land under ditch, not included in reservations, This area is nearly surrounded by small mountain ranges, mostly of granite, and is intersected by the Salt River, whose bed here extends nearly from east to west. The general slope of the tillable portions of the valley is to the southwest, the grades being easy and favorable to the distribution of irrigation water. Of the total area under ditch, about 177,000 acres lie north of the river,* and 115,000 acres to the south.†

The map will show that this region is the meeting place of waters from a wide extent of country. The Salt River drains a portion of Eastern Arizona, and unites with the Rio Verde and Agua Frio rivers, which carry a large portion of the drainage of Central Arizona. The alluvial soils of the valley, at the lower

*Qn authority of W. D. Fulwiler, Arizona Improvement Co., Phoenix.
†On authority of A. J. Chandler, Consolidated Canal Co., Mesa City.

levels. are therefore built up from the wash of two widely separated regions, as well as that from the adjacent mountain slopes. Partly for this reason, and also because of the action of water, the soils of the valley are varied in chemical and physical character. Through the action of water, especially, in separating earth materials into coarser and finer portions, the lower alluvial lands are very varied in character, often changing within a few hundred feet from light loams or sands to heavy clays. On the higher slopes of the valley, where the action of local storm waters is more uniform, the soil formations are more regular, running gradually from coarse rocks and gravel on the higher slopes to sands, loams, and clays below.

The work of soil examination for a region of such varied character must evidently be very extended before general statements can be made, and this bulletin is intended to record the results thus far obtained from the study of a series of samples thought to fairly represent the various types of virgin soils found in the cultivated portions of the valley. The samples were taken by the writer, and in each instance represent the first twelve inches of soil. They were taken in nearly every case at a dry time of the year, when the alkaline salts were mostly near the surface and were consequently included in the sample.

A statement of the results obtained, however, should be preceded by at least a short review of current notions regarding the interpretation and value of soil analysis.

THE OBJECT OF SOIL ANALYSIS.

In order to understand the object of soil analysis it is essential to bear in mind the relation of the soil to growing crops. In the first place, it affords a foothold to vegetation, acts as a store-house of the sun's warmth, and is the dwelling place of useful species of bacteria which add to soil fertility. The main thing, however, which concerns us in connection with soil examination is its use as a provider of certain plant foods to growing crops, These plant foods are, chiefly, water, nitrogen compounds, and various minerals containing potash, lime, magnesia, iron, phosphoric acid, sulphuric acid and chlorine.

Of these materials, water is consumed in far the greatest amount. Not only is it used to build up vegetable tissues, but enormous quantities of it evaporate from the leaves after assisting in the development of the plant. Experiments by Professor King of Wisconsin show that to form one pound of dry matter barley requires 393 pounds of water, clover requires 453 pounds, and potatoes require 423 pounds. Other investigators obtain even larger figures. Nearly all of the materials built into the tissues of the common crops are derived from water, carbon dioxide, and nitrogen compounds. 94 per cent is a fair average of clover, timothy, flax, potatoes, sugar-beets, wheat, rye, oats, and barley. The remaining six per cent is solid mineral ash, consisting in part of the essential compounds mentioned above. The following table presents average figures for plant foods required by barley, clover and potatoes:

Plant food required for 100 pounds of dry matter.

	Barley	*Clover.*	*Potatoes*	*Averages.*
	lbs.	lbs.	lbs.	lbs.
Water required for the crop	39,300	45,300	42,300	42,300
Water, carbon dioxide, nitrogen compounds, etc., which are converted into vegetable matter	94.34	93.24	96.43	94.67
Essential mineral compounds; potash, lime, magnesia, iron-oxide, phosphoric acid, sulphuric acid and chlorine	2.734	6.419	3.432	4.195

In these instances it appears that, on the average, *each hundred pounds of dry substance formed, requires 4.2 pounds of solid mineral plant foods, and no less than 42,300 pounds of water, or about ten thousand times as much.* In the complete plant ration therefore, the solid mineral constituents are mere pepper and salt so far as quantity goes, although they, no less than water itself, are essential to plant life.

THE KIND OF EXAMINATION NEEDED.

It is evident, therefore, that the examination of soils must be made with reference to their power to supply water, as well as solid plant foods, to growing crops.

Physical Analysis: Now, the water available to plants, other things being equal, depends chiefly upon the physical make up of the soil, that is to say, upon the size of the soil particles, upon then arrangement, either singly or in groups, and to some extent upon their chemical composition. In general, soils made up of finer particles, such as clays and heavy loams, will hold more water than sandy or gravelly soils, but the motion of water through them is slower, and its loss by drainage and surface evaporation is less rapid. In connection with irrigation, therefore, heavy soils containing much clay, usually take water less rapidly, but when once well moistened will, with proper cultivation, afford more moisture to the crop through a longer period of time. On the other hand, coarse grained soils are quickly saturated with water when irrigated, but hold less of it and dry out sooner by drainage and evaporation. They, therefore, have less drouth-resisting power, although easier to irrigate and cultivate. In connection with the physical make up of a soil it is also important to consider the nature of the plant roots themselves. Trees and vines, whose long roots can go to great distances after water, usually do well in sandy soils, while shallow rooted crops, which require that a gradual supply of water shall be delivered near the surface, will often do best in heavier soils.

The object of a physical analysis, therefore, is to classify a soil according to the prevailing size of its particles, since its behavior with water mainly depends upon this feature. Knowing accurately the physical type, such as clay, silty, or sandy, we may derive a fair notion of its behavior with water and under cultivation, and it is consequently possible to give good reasons for the choice of certain lands for particular crops.

In the absence of a physical examination, however, practical information may be obtained by observing the water holding power, the hygroscopic moisture which a soil can take up from moist air, and the rapidity with which water will percolate downwards through a soil, or rise by capillary motion to the surface.

Chemical Analysis: Agricultural experience has shown that, under average conditions, certain amounts of mineral plant food in easily soluble form, are essential to a fertile soil. *The object, therefore, of chemical analysis is to determine, as far as possible, the amounts of plant food available to vegetation under proper physical conditions,* and from this knowledge to determine any cause of barrenness due to a deficiency in the soil, and form a judgment as to the kind of fertilization which will be needed in connection with the culture of certain crops.

But a chemical analysis must always he considered in connection with the physical nature of a soil. To illustrate: a clay soil, naturally of close texture and impervious to roots or water, perhaps lumpy, also, through poor cultivation, may be chemically rich but practically barren because its compactness makes it difficult for roots to reach and use its stores of plant food. A sandy or silty soil, on the other hand, may show less of phosphoric acid, lime, nitrogen or potash, but if its loose texture allows a wheat crop, for instance, to send its roots five feet instead of two, it may easily supply a greater actual amount of essential plant food to the crop.

ESSENTIAL PLANT FOODS

The substances supplied from the soil, essential to plant growth, are certain of the compounds of nitrogen, potash, lime, magnesia, iron, phosphoric acid, sulphuric acid and chlorine. The other constituents determined in a complete analysis, such as silica, alumina, soda, and manganese oxide, though usually present in plant ashes, are not essential to vegetable life. Among the essential constituents, the compounds of magnesia, iron, sulphuric acid, and chlorine are almost universally present in soils in sufficient amount for thrifty plant growth. Nitrogen, potash, lime, and phosphoric acid, however, upon which plants usually draw more heavily, may be present in less than the amount needed to ensure fertility. Consequently, the percentages of these constituents in a soil must be more particularly considered in connection with crop producing power.

Nitrogen is a constituent of vegetable albumins and is therefore always present in large amount in growing plants, especially in their younger parts. This plant food is required in the form of nitrates, resulting from the action of various bacterial ferments upon vegetable and other compounds present in the soil. The existence of these bacteria depends upon suitable conditions of temperature, air, and soil moisture, so that skilful cultivation is closely responsible for the formation and supply of this leading plant food. Leguminous plants, such as clover, beans, vetches, and alfalfa, also aid in the work of supplying nitrogen to vegetation by maintaining various peculiar species of bacteria upon their roots These bacteria, growing in colonies which appear as tubercles or nodules upon the roots, have the power to convert atmospheric nitrogen into the desirable nitric form available to plants.

As a rule, not less than 0.1 per cent of nitrogen, in its various combinations, is necessary for a fertile soil.

Potash is believed to aid in the formation of certain organic substances in plants, such as starch. It is also found in plant tissues combined with vegetable acids which in the free state would be injurious. It comprises a very large proportion of the ash of vegetable substances, from 10 to 60 per cent being common It must therefore be abundantly available in the soil. It is chiefly supplied in the forms of potassium sulphate, chloride phosphate, nitrate, and silicate.

From 0.2 to 0 3 per cent of available potash, as determined by the standard methods of soil anlysis, is considered essential for fertility. In sandy soils, less than this percentage may be sufficient, while heavy clays may require more.

Phosphoric acid supplies the phosphorus needed for the construction of numerous vegetable substances. The phosphate of potash is also believed to aid in transferring vegetable albumin from the leaves to the seeds of plants. The ash of vegetable products commonly contains from 5 to 50 per cent of phosphoric acid, which is chiefly supplied in the form of phosphates of calcium.

0.1 per cent of phosphoric acid is commonly considered ample for a fertile soil.

Lime is essential both as a plant food and for its chemical and physical effects upon the soil. In the plant, as well as in the soil, it combines with acids which would be injurious in the free state. It is found in all plant ashes, from 1 to 30 per cent being observed, and is supplied as calcium sulphate, nitrate, phosphate, and carbonate.

In the soil itself, lime, by combining with vegetable humus, hinders its decomposition and loss, and also renders phosphoric acid and potash more available for the use of plants. Its most important office, however. is to improve the physical condition, especially of heavy soils, by cementing the finer particles of silt and clay into floccules or grains, thus making the general mass more pervious to air and water, and improving its tilling qualities.

The amount of lime necessary for fertility varies according to the kind of soil. Clay soils require much more lime than sandy ones. Dr. Hilgard states that 0.1 per cent of lime is necessary for a light sandy soil, while 0.5 per cent is required for a heavy clay,—as much as 1.0 or 2.0 per cent often being desirable.

Magnesia is known to be essential to plant growth, although its use is not understood. The ash of common crops contains from 1 to 15 per cent of it. It is supplied chiefly as sulphate and carbonate, and is rarely deficient in soils,

Iron is necessary for the formation of the chlorophyll grains, which give green color to thrifty vegetation and upon which depends the assimilation of carbon dioxide by the plant, with the resulting formation of organic substances.

Although of the greatest importance, iron is usually contained in plant ashes in but small amount, from .05 to 2.0 or 3.0 per cent being common. It is supplied from the soil chiefly as oxide and hydrate. Small amounts are sufficient, and it is never in deficient quantity.

Sulphur is a constituent of albumin and other vegetable compounds. It is supplied in the sulphates of lime, potash, and other bases. Very small amounts are sufficient for the needs of plants and most soils contain an abundance of its combinations.

Chlorine is believed to aid in the removal of starch from the leaves to the stems and roots of plants. Traces only are needed for this purpose, and it is usually supplied in the form of common salt.

Soda, though always present in plant ashes, is not considered an essential plant food.

Manganese oxide, likewise, is not essential to plant growth.

CHEMICAL DETERMINATIONS BELATED TO PHYSICAL CHARACTER.

Some items shown by chemical analysis are of no direct value in plant nutrition themselves, but throw much light upon the physical character of soils.

The Insoluble Residue consists mainly of the coarser parts of the soil and therefore indicates roughly the proportion of sand present.

Soluble Silica and Alumina, though usually present in considerable amount in plant ashes, are not indispensable to plant life. As obtained from the soil by chemical analysis, they are associated in part with clay, upon which so largely depends the physical character of soils, such as their behavior with water and under cultivation. In the absence of a mechanical analysis, therefore, a rough estimate of comparative amounts of clay in different soils may be formed from the silica and alumina present. Iron, in the form of finely divided hydrates, may also come from the finer portions of the soil, classed mechanically as clay.

Humus is of great importance both in its relation to the physical condition of soils and in the nutrition of plants. It results from the partial decay of organic matter, such as barnyard manure, roots, stubble, and leaves. Humus, especially in limy soils, resists decay to some extent, but gradually disappears under the influence of air and heat.

Its physical effects are: 1. To increase the water-holding power of soils and hinder its loss by drainage and evaporation, thus improving drouth resisting power. 2. To improve tilth by helping to loosen and flocculate soils. 3. To increase the capacity of the soil for warmth by darkening its color.

In the nutrition of plants the usefulness of humus consists in its power to act as a storehouse for nitrogen and mineral plant foods. It contains from less than 5 per cent of nitrogen in humid climates to more than fifteen per cent in arid regions. Through the action of soil ferments humic nitrogen is gradually converted into nitrates for the use of plants. More than this, it has been shown that humus seizes upon the mineral plant foods of the soil—potash, lime, and phosphoric acid among the number, and converts them into forms readily available to vegetation*

Arid soils are especially liable to a deficiency of humus, which is most rapidly destroyed under conditions of heat and dryness, and one of the most important agricultural problems for regions of this character is that of the renewal of this important material

Alkaline salts, so well and unhappily known by all dwellers in arid regions, consist for the most part of sodium carbonate, or sal-soda; sodium sulphate, or Glauber's salts; and sodium chloride, or common salt. Sulphates and chlorides of calcium, magnesium, and potash, and small amounts of nitrates and phosphates are also commonly present. The most injurious of these salts is sodium carbonate or "black alkali." "White alkali," consisting chiefly of sodium sulphate and sodium chloride, is much less to be dreaded

The amount of alkaline salts which may exist in a soil without injury to vegetation depends upon the kind of salts, the char acter of the soil, and the crop.

On this point Dr Hilgard says that for barley the largest amount of alkaline salts that can be tolerated in the soil and subsoil, under otherwise favorable conditions, and with salts consisting of not over half of carbonate of soda, lies somewhere between .159 and .203 per cent of the soil. Again, Dr. Hilgard states that sugar beets of good and even high grade, both as to sugar and purity, may be grown on lands containing about 3 per cent of alkaline salts in the first three feet of soil, the quality of beets depending upon the nature of the salts.

The same authority has noticed that .074 per cent of sodium carbonate killed barley, while good sugar beets could be grown in soil containing .076 per cent of the same salt.

WATER TESTS.

The drainage and capillary water tests shown in the tables are for the purpose of giving an approximate idea of the comparative rapidity with which different soils will take irrigation water, and will lose it by drainage and surface evaporation. These figures, and those for water holding capacity, are related to the drouth resisting power of the soil,—a most important consideration in a semi-arid region.

The drainage test represents the amount of water percolating in 24 hours through 25 grams (nearly an ounce) of soil, loosely packed in a vertical f inch tube. The tube was so arranged that a column of water 7½ inches deep stood over the soil, and had free outlet below.

Before beginning the test the soil was moistened from below by placing the foot of the tube in water and allowing it to become moist by capillary action. The amounts of water draining through the tubes under these conditions varied enormously with different soils and give a good comparative notion of their leachiness. The smallest amount of leaching noted was 2 4 cubic centimeters; the largest was no less than 842 cubic centimeters. In general, sandy soils leach more rapidly, while those containing clay and fine silts leach with difficulty.

The capillary water test states the time required for water to rise by capillary attraction through a six inch column of soil loosely packed in a | inch tube. The time was observed to vary from 35 minutes to 8 days in different cases. In general, the capillary motion is slower in soils containing clay and finer materials, and more rapid in those of sandy character.

INTERPRETATION OF ANALYSES.

The questions which a soil analysis is expected to answer relate to its crop producing power, and, as noted above, so far as the soil is concerned, this depends upon both physical and chemical composition. In the following pages the results are stated so that those figures which are more particularly related to physical character stand by themselves in the upper half of the tables. The more important plant foods—potash, lime, phosphoric acid, and nitrogen, also humus, are printed in italics. In considering the analyses, the following percentages of the more important constituents commonly needed for a fertile soil may be borne in mind:

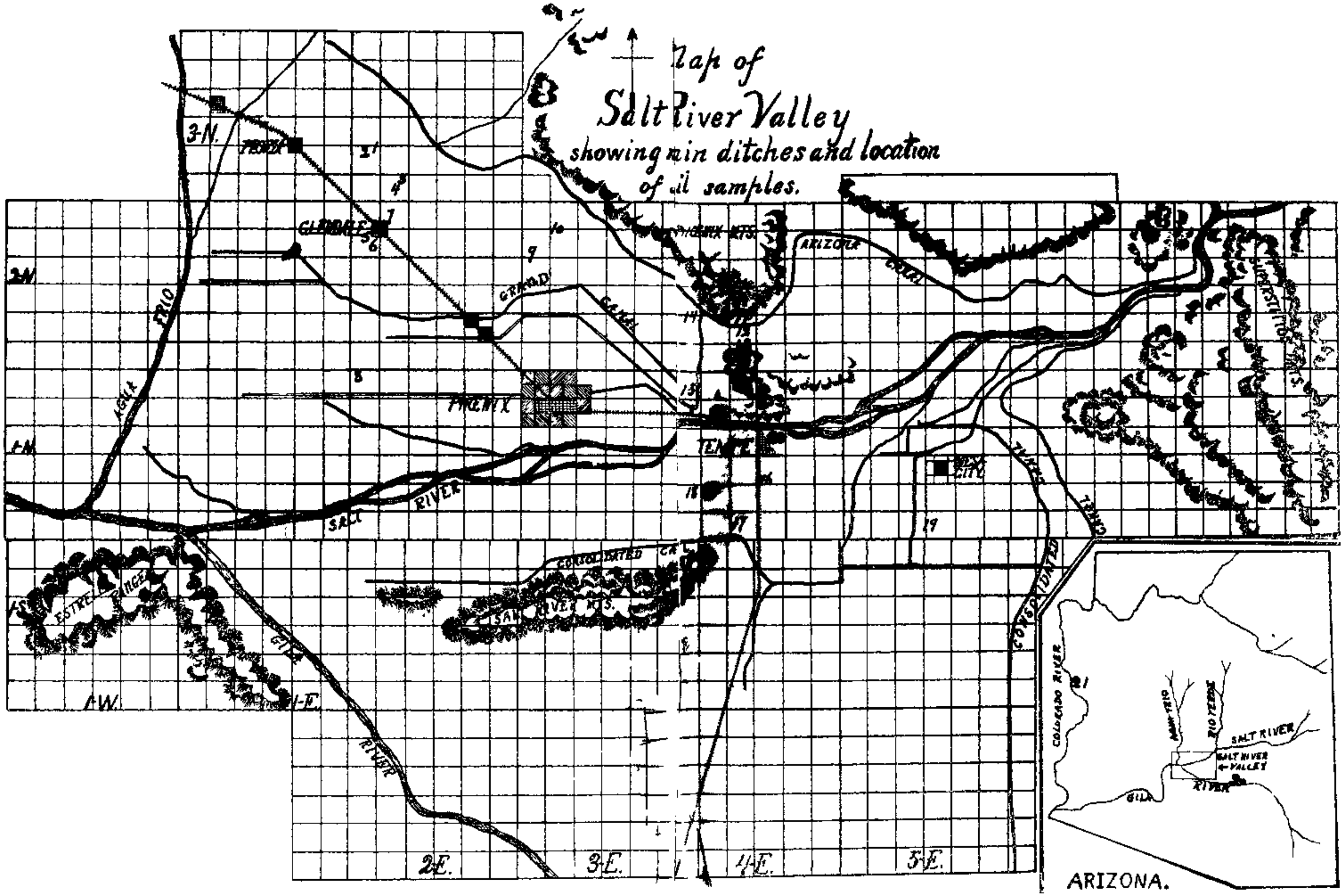
Nitrogen, not less than .10 per cent, usually.

Potash, .20 to .30 per cent.

Phosphoric acid, not less than .05 per cent, while .10 per cent is desirable.

Lime, at least .10 per cent in light sandy soils, and at least .50 per cent in heavy clay soils.

Certain of the water tests and chemical percentages may be used for interpreting the physical character of the samples. The



Salt River Valley
showing main ditches and location
of soil samples.
3-N.
2-N.
1-N.
1-W.
1-E.
2-E.
3-E.
4-E.
5-E.
GLENDALE
PHENIX
TEMPE
MESA CITY
ARIZONA CANAL
GRAND CANAL
CONSOLIDATED CANAL
TEMPE CANAL
SALT RIVER
GILA RIVER
AGUA FRIO
ESTRELLA RANGE
SALT RIVER MTS.
PHENIX MTS.
SUPERSTITION MTS.
ARIZONA.
COLORADO RIVER
AGUA FRIO
RIO VERDE
SALT RIVER
SALT RIVER VALLEY
GILA
RIVER

following table gives an approximate classification, which, however, is intended to apply only to the analyses in this bulletin

	Heavy soils, good alfalfa lands	*Loamy soils on which grains succeed*	*Light soils suitable Jot vines and trees.*
Insoluble matter	Less than 55%	55 to 65%	More than 65%
Soluble silica	More than 16%	12 to 16%	Less than 12%
Alumina	" " 8%	5 to 8%	" " 6%
Drainage test	Up to 50 c. c	50 to 125 c c.	More than 125 c. c.
Capillary test	More than 10 hs	5 to 10 hours.	Less than 5 hrs
Maximum water capacity	Above 40%	35 to 40%	Less than 35%

In all cases it must be remembered that the samples analyzed are of surface soil, and that in each instance the estimate of its productive power may be qualified by the existence of limy hardpan at various depths below the surface. This hardpan, concerning which more will be said, often occurs so near the surface as manifestly to interfere with root development. Detailed observations on this feature have not been made in connection with each soil sample, but residents of the valley, with the aid of the map and their knowledge of particular localities will be able to supply this information for their own benefit.

The analytical work was executed according to the official methods of analysis, by Mark Walker, Jr., assistant chemist of the station.

The map shows the location by number of the various soils analyzed. Most residents of the valley will be familiar with many of the localities sampled and, by comparison, will be able to apply the information to their own lands,

Soils 8 and 4, taken from the Baxter Ranch, near Glendale, within a quarter of a mile of each other, give us a fair idea of the sort of soil required for grapes, and why. Soil No. 4 supports an excellent vineyard of "Thompson's Seedless" vines, while upon No. 3 vines are a failure. Except in the case of lime, No, 4, though practically a better soil for vines, is poorer in all the more important plant foods than No. 3. It contains, however, much more gravel and insoluble matter, and is more permeable to water. The vital difference between these two soils, therefore, is a physical one. No. 4, being of loose and sandy texture, takes irrigation water easily, and is readily penetrated to great distances by the extensive root systems of vines. Soil No. 3, on the other hand, is of closer texture, takes water with difficulty, as shown by field experience and the drainage test in the table, and

Soil No. 3, Sec. 32, T. 3 N., R. 2 E., Baxter Ranch, north end, adobe soil, unfit for grapes.

Gravel, coarser than .5 m.m.	1.74%	Water tests:	
Fine earth	98.26	Moisture in air-dry soil	3.542%
In fine earth, water-free:		Hygroscopic moisture	8.25
Insoluble matter—sand, etc.	54.255	Drainage test	8 c. c.
Soluble silica—from clay "	18.880	Capillary water test	16h-46m
Alumina (Al_2O_3) " " "	8.856	Maximum water capacity	43.96%
Iron oxide (Fe_2O_3) " " "	6.454	Minimum " "	21.66
Organic and volatile matter	4.976		
Lime (CaO)	*2.213*		
Potash (K_2O)	*.955*	Other determinations:	
Soda (Na_2O)	.603	*Humus*	*.678%*
Magnesia (MgO)	2.535	*Nitrogen*	*.044*
Manganese oxide (Mn_3O_4)	.050	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.244*	Total soluble salts	.318
Sulphuric acid (as SO_3)	.045	Sodium carbonate	.036
Carbonic acid (as CO_2)	.443	Sodium sulphate	.044
Chlorine	.085	Sodium chloride	.140
Net total*	100.575		

Soil No. 4, Sec. 32, T. 3 N., R. 2 E., Baxter Ranch, south end, sandy soil of "Thompson's Seedless" Vineyard.

Gravel, coarser than .5 m.m.	4.74%	Water tests:	
Fine earth	95.26	Moisture in air-dry soil	2.089%
In fine earth, water-free:		Hygroscopic moisture	4.560
Insoluble matter—sand, etc.	65.750	Drainage test	129 c.c.
Soluble silica—from clay "	12.555	Capillary water test	1h–26m
Alumina (Al_2O_3) " " "	5.611	Maximum water capacity	36.67%
Iron oxide (Fe_2O_3 " " "	5.818	Minimum water capacity	18.88
Organic and volatile matter	2.881		
Lime (CaO)	*3.028*		
Potash (K_2O)	*.528*	Other determinations:	
Soda (Na_2O)	.364	*Humus*	*.300*
Magnesia (MgO)	1.991	*Nitrogen*	*.029*
Manganese oxide (Mn_3O_4)	.060	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.148*	Total soluble salts	.193
Sulphuric acid (as SO_3)	.053	Sodium carbonate	.032
Carbonic acid (as CO_2)	1.296	Sodium sulphate	.090
Chlorine	.023	Sodium chloride	.038
Net total*	100.101		

*Sum total minus excess of oxygen due to chlorine.

Note: The term "clay" as used in these tables refers to the finer portions of the soil, which may include not only kaolin, or true clay, but zeolites, ferric hydrate, and other compounds.

does not afford ready passage to extensive root systems. These two cases are excellent illustrations of the great influence of physical composition upon the value of soils. The nature of this difference is shown by the following mechanical analysis of these soils into three general divisions, classed according to fineness:

Constituents of water-free soil.	*No. 3, heavy soil.*	*No. 4, light soil.*
	per cent.	per cent.
Coarser portion, sands, .5 to .05 m. m. diameter.	25.17	56.27
Medium portion, silts, .05 to .005 m. m. diameter.	46.58	32.06
Fine portion, clay, less than .005 m. m. diameter.	24.06	7.68
Organic and volatile matter	4.90	4.05
Totals	100.71	100.06

The looser texture of soil No. 4, containing twice as much sand, less silt, and one-third as much clay as No. 3, is thus plainly accounted for.

The low percentage of nitrogen in both samples is noticeable, and these soils are likely to show a deficiency of this element first, if indeed, they are not nitrogen-hungry in their original state.

In both cases an abundance of potash and phosphoric acid are present, also lime, but only partly in the more useful form of carbonate. Alkaline salts are not present in excessive amount.

Soils 5 and 6, from the Arizona Improvement Company's section near Glendale, again illustrate the characteristics of a good fruit soil in this region. No. 6 is from a very prosperous apricot orchard, while No. 5 does not do well with either grapes or trees, although it is richer in potash, phosphoric acid and nitrogen than the other soil. The vital difference, as in the preceding pair of samples, is a matter of physical texture. No. 6 contains more gravel and insoluble matter, and consequently takes water more readily, as shown by the drainage test. Because of its looser texture it allows the roots of vines and trees to penetrate easily through a greater depth of soil so that in spite of smaller percentages, a greater actual amount of plant food is probably available to these forms of vegetation.

These soils are well supplied with potash, lime, and phosphoric acid, but are apparently low in nitrogen and humus. They are but slightly alkaline.

Soil No. 5, Arizona Improvement Co., Sec. 7, T. 2 N., R. 2 E., N. W. quarter. Adobe soil which does not take water well, and is not suitable for grapes or trees.

Gravel, coarser than .5 m.m.	.92%	Water tests:	
Fine earth	99.08	Moisture in air-dry soil	3.454%
In fine earth, water-free:		Hygroscopic moisture	7.358
Insoluble matter—sand, etc.	54.895	Drainage test	18 c. c.
Soluble silica—from clay "	18.685	Capillary water test	9h–40m
Alumina (Al_2O_3) " " "	8.276	Maximum water capacity	43.87%
Iron oxide (Fe_2O_3) " " "	6.153	Minimum " "	18.57
Organic and volatile matter	3.895		
Lime (CaO)	*2.721*		
Potash (K_2O)	*.777*	Other determinations:	
Soda (Na_2O)	.468	*Humus*	*.571*
Magnesia (MgO)	2.441	*Nitrogen*	*.043*
Manganese oxide (Mn_3O_4)	.050	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.220*	Total soluble salts	.149
Sulphuric acid (as SO_3)	.045	Sodium carbonate	.030
Carbonic acid (as CO_2)	1.003	Sodium sulphate	.034
Chlorine	.035	Sodium chloride	.058
Net total	99.656		

Soil No. 6, Arizona Improvement Co., Sec. 7, T. 2 N., R. 2 E, from apricot orchard. An excellent soil for vines and fruit trees.

Gravel, coarser than .5 m.m.	4.15	Water tests:	
Fine earth	95.85	Moisture in air-dry soil	1.832%
In fine earth, water-free:		Hygroscopic moisture	4.295
Insoluble matter—sand etc.	67.270	Drainage test	83 c. c.
Soluble silica—from clay "	11.875	Capillary water test	4h–1m
Alumina (Al_2O_3) " " "	5.428	Maximum water capacity	31.38%
Iron oxide (Fe_2O_3) " " "	5.352	Minimum " "	9.957
Organic and volatile matter	2.769		
Lime (CaO)	*2.883*		
Potash (K_2O)	*.472*	Other determinations*	
Soda (Na_2O)	.410	*Humus*	*.708*
Magnesia (MgO)	2.025	*Nitrogen*	*.033*
Manganese oxide (Mn_3O_4)	.085	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.140*	Total soluble salts	.162
Sulphuric acid (as SO_3)	.051	Sodium carbonate	.102
Carbonic acid (as CO_2)	1.283	Sodium sulphate	.036
Chlorine	.019	Sodium chloride	.032
Net total	100.058		

Soils 11, 10 and 17 fairly represent the orange belt of the Salt River Valley. They are all rich in potash and lime, but Nos. 11 and 17 are somewhat low in phosphoric acid. This defect, if such, would tend to be offset by the abundance of lime and by the sandy nature of the soil. The humus and nitrogen percent-

Soil No. 11, Sec. 28, T. 2 N., R. 4 E., from south slope of Granite Mountain, on which orange trees do well.

Gravel, coarser than .5 m.m.	29.39%	Water tests:	
Fine earth	70.61	Moisture in air-dry soil	2.038%
In fine earth, water free:	——	Hygroscopic moisture	4.782
Insoluble matter—sand etc.	71.975	Drainage test	241 c. c.
Soluble silica—from clay "	10.305	Capillary water test	1h–19m
Alumina (Al_2O_3) " " "	5.139	Maximum water capacity	33.71%
Iron oxide (Fe_2O_3) " " "	4.212	Minimum " "	10.39
Organic and volatile matter	3.208		
Lime (CaO)	*2.068*		
Potash (K_2O)	*.671*	Other determinations:	
Soda (Na_2O)	.232	*Humus*	*.285*
Magnesia (MgO)	1.391	*Nitrogen*	*.033*
Manganese oxide (Mn_3O_4)	.029	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.059*	Total soluble salts	.051
Sulphuric acid (as SO_3)	.019	Sodium carbonate	.036
Carbonic acid (as CO_2)	.848	Sodium sulphate	.006
Chlorine	.005	Sodium chloride	.009
Net total	100.160		

Soil No. 10, Orangewood, Sec. 5, T. 2 N., R. 3 E., mesa soil in oranges.

Gravel, coarser than .5 m.m.	6.97%	Water tests:	
Fine earth	93.03	Moisture in air-dry soil	1.841%
In fine earth, water-free:	——	Hygroscopic moisture	4.161
Insoluble matter—sand etc.	68.870	Drainage test	143 c. c.
Soluble silica—from clay "	10.855	Capillary water test	1hr-48m
Alumina (Al_2O_3) " " "	5.702	Maximum water capacity	35.02%
Iron oxide (Fe_2O_3) " " "	5.165	Minimum " "	14.715
Organic and volatile matter	2.951		
Lime (CaO)	*2.453*		
Potash (K_2O)	*.630*	Other determinations:	
Soda (Na_2O)	.282	*Humus*	*.612*
Magnesia (MgO)	1.668	*Nitrogen*	*.036*
Manganese oxide (Mn_3O_4)	.050	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.112*	Total soluble salts	.081
Sulphuric acid (as SO_3)	.037	Sodium carbonate	.027
Carbonic acid (as CO_2)	1.158	Sodium sulphate	.024
Chlorine	.011	Sodium chloride	.018
Net total	99.942		

ages are low. Alkaline salts are in no case present in injurious quantity. The large percentages of gravel and insoluble matter tally with the good drainage tests and the rapid capillary action and show these soils to be receptive to water and of loose texture. Consequently their fitness for trees is explained, although they undoubtedly stand in need of enrichment in nitrogen, humus, and, in the case of Nos. 11 and 17, probably phosphoric acid also.

Soil No. 17, N. W. quar., Sec. 33, T. 1 N., R. 4 E., red soil south of James Carroll's, S. W. of Tempe.

Gravel, coarser than .5 m. m.	32.31%	Water tests:	
Fine earth	67.69	Moisture in air-dry soil	1.689%
In fine earth, water-free:		Hygroscopic moisture	3.952
Insoluble matter—sand etc.	74.290	Drainage test	200 c. c.
Soluble silica—from clay "	9.799	Capillary water test	1h–4m
Alumina (Al_2O_3) " " "	5.058	Maximum water capacity	32.53%
Iron oxide (Fe_2O_3) " " "	3.975	Minimum " "	10.96
Organic and volatile matter	2.177		
Lime (CaO)	*1.336*		
Potash (K_2O)	*.783*	Other determinations:	
Soda (Na_2O)	.206	*Humus*	*.558*
Magnesia (MgO)	1.317	*Nitrogen*	*.038*
Manganese oxide (Mn_3O_4)	.055	Alkaline salts	
Phosphoric acid (as P_2O_5)	*.080*	Total soluble salts	.106
Sulphuric acid (as SO_3)	.045	Sodium carbonate	.056
Carbonic acid (as CO_2)	.516	Sodium sulphate	.021
Chlorine	.011	Sodium chloride	.017
Net total	99.646		

Soil 14 represents portions of W. M. Ward's orange orchard in which the trees are not doing well. The reason is apparent when we consider the large amount of coarse gravel in this soil. The percentages of phosphoric acid and nitrogen in the fine earth alone are scant, but when diluted by twice as much gravel as fine earth they are undoubtedly reduced below the point of sufficiency, even in a loose and permeable soil. This soil also requires peculiar care in cultivation. If irrigation is not followed by cultivation just at the right time it is stated to break up into unmanageable lumps. This is due to the physical makeup of the soil. The analysis indicates that the sample consists of a large percentage of coarser materials with a small amount of clay. Such physical composition causes poor tilth when the proportions are such that the clay acts as a cement for

the larger particles. This soil quite certainly stands in need of liberal fertilization with manures containing phosphoric acid, nitrogen, and organic matter. Barnyard manure, properly rotted and worked in, and alfalfa plowed under as green manuring, would aid in its improvement.

Soil No. 14, W. M. Ward's orange orchard, Sec. 30, T. 2 N., R. 4 E., similar to ground in which orange trees do not thrive.

Gravel, coarser than .5 m.m.	64.61%	Water tests:	
Fine earth	35.39	Moisture in air-dry soil	1.711%
In fine earth, water-free:		Hygroscopic moisture	3.225
Insoluble matter—sand etc.	75.020	Drainage test	105 c. c.
Soluble silica—from clay "	9.579	Capillary water test	2h–29m
Alumina (Al_2O_3) " " "	4.764	Maximum water capacity	25.65
Iron oxide (Fe_2O_3) " " "	4.673	Minimum " "	7.581
Organic and volatile matter	2.049		
Lime (CaO)	*1.354*		
Potash (K_2O)	*.593*	Other determinations:	
Soda (Na_2O)	.246	*Humus*	*.453*
Magnesia (MgO)	1.188	*Nitrogen*	*.030*
Manganese oxide (Mn_3O_4)	.070	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.058*	Total soluble solids	.142
Sulphuric acid (as SO_3)	.034	Sodium carbonate	.030
Carbonic acid (as CO_2)	.209	Sodium sulphate	.028
Chlorine	.009	Sodium chloride	.016
Net total	99.844		

Soil No. 1 represents the lower and heavier ground of the almond orchards on the Salmon ranch, north of Glendale, managed by Mr. H. W. Adams. At the time of taking the samples, the trees in these parts of the orchard were much affected with root-knot. It is not possible to connect this unhealthy condition with any special peculiarity of the soil. Potash is abundant; phosphoric acid and nitrogen, as usual, are scant. The alkaline salts are not present in injurious amount. The most notable feature of this sample is the entire absence of lime in the useful form of carbonate, and it is possible that this peculiarity, together with the heavy character of this soil, results in a dense condition unfavorable to root development. Barnyard manure and green manuring would undoubtedly be of benefit on this land.

Soil No. 2 represents the higher portions of the same almond orchard, on which trees prospered better. It shows much more lime and phosphoric acid, but, as usual, is low in humus and nitrogen. The low maximum water capacity, the high drainage test, and rapid capillary movement, indicate that this soil, though easily irrigated, is a poor drouth-resister.

Soil No. 1, Sec. 30, T. 3 N., R. 2 E., north of Glendale, from low ground north of Adams' almond orchard. Heavier soil.

Gravel, coarser than .5 m.m.	10.66%	Water tests:	
Fine earth	89.34	Moisture in air-dry soil	3.201%
In fine earth, water-free:		Hygroscopic moisture	6.964
Insoluble matter—sand, etc.	63.525	Drainage test	75 c. c.
Soluble silica—from clay "	15.690	Capillary water test	6h–8m
Alumina (Al_2O_3) " " "	7.743	Maximum water capacity	35.55%
Iron oxide (Fe_2O_3) " " "	4.918	Minimum " "	15.62
Organic and volatile matter	3.967		
Lime CaO)	*.981*		
Potash (K_2O)	*1.025*	Other determinations:	
Soda (Na_2O)	.331	*Humus*	*.706*
Magnesia (MgO)	1.764	*Nitrogen*	*.044*
Manganese oxide (Mn_3O_4)	.078	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.053*	Total soluble salts	.092
Sulphuric acid (as SO_3)	.040	Sodium carbonate	.023
Carbonic acid (as CO_2)	.000	Sodium sulphate	.024
Chlorine	.012	Sodium chloride	.020
Net total	100.124		

Soil No. 2, Sec. 30, T. 3 N., R. 2 E., north of Glendale, from high knoll north of Adams' almond orchard. Lighter soil.

Gravel, coarser than .5 m.m.	38.22%	Water tests:	
Fine earth	61.78	Moisture in air-dry soil	1.711%
In fine earth, water-free:		Hygroscopic moisture	3.894
Insoluble matter—sand etc.	73.654	Drainage test	200 c. c.
Soluble silica—from clay "	9.821	Capillary water test	1h–40m
Alumina (Al_2O_3) " " "	4.842	Maximum water capacity	25.20%
Iron oxide (Fe_2O_3) " " "	5.065	Minimum " "	7.72
Organic and volatile matter	2.784		
Lime (CaO)	*1.282*		
Potash (K_2O)	*.563*	Other determinations:	
Soda (Na_2O)	.275	*Humus*	*.400*
Magnesia (MgO)	1.356	*Nitrogen*	*.046*
Manganese oxide (Mn_3O_4)	.044	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.122*	Total soluble salts	.172
Sulphuric acid (as SO_3)	.026	Sodium carbonate	.058
Carbonic acid (as CO_2)	.206	Sodium sulphate	.010
Chlorine	.011	Sodium chloride	.018
Net total	100.049		

Soil No. 9, virgin desert near Orangewood, Sec. 7, T. 2 N., R. 3 E.

Gravel, coarser than .5 m.m.	8.36%	Water tests:	
Fine earth	91.64	Moisture in air-dry soil	2.854%
In fine earth, water-free:		Hygroscopic moisture	6.079
Insoluble matter—sand etc.	65.195	Drainage test	60 c. c.
Soluble silica—from clay "	14.690	Capillary water test	5h–44m
Alumina (Al_2O_3)" " "	7.104	Maximum water capacity	34.65%
Iron oxide (Fe_2O_3)" " "	4.664	Minimum " "	13.57
Organic and volatile matter	3.778		
Lime (CaO)	*1.284*		
Potash (K_2O)	*.860*	Other determinations:	
Soda (Na_2O)	.299	*Humus*	*.679*
Magnesia (MgO)	1.713	*Nitrogen*	*.012*
Manganese oxide (Mn_3O_4)	.104	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.106*	Total soluble salts	.087
Sulphuric acid (as SO_3)	.048	Sodium carbonate	.035
Carbonic acid (as CO_2)	.226	Sodium sulphate	.037
Chlorine	.009	Sodium chloride	.015
Net total	100.078		

Soil No. 9, which represents a considerable tract of rather high ground west of Orangewood, shows a character of soil suitable for vines or trees. It is fairly supplied with potash and phosphoric acid, is medium in lime, and scant in nitrogen. It is rather light, fairly porous to water, and apparently stands drouth well, as shown by its slow capillary test and medium water holding power. The alkaline salts are low.

Soil No. 7, Sec. 5, T. 2. N., R. 2 E., near Glendale.

Gravel, coarser than .5 m.m.	.42%	Water tests:	
Fine earth	99.58	Moisture in air-dry soil	2.947%
In fine earth, water-free:		Hygroscopic moisture	6.656
Insoluble matter—sand etc.	55.515	Drainage test	38 c. c.
Soluble silica—from clay "	18.460	Capillary water test	5h–38m
Alumina (Al_2O_3)" " "	8.050	Maximum water capacity	43.96%
Iron oxide (Fe_2O_3)" " "	6.222	Minimum " "	18.21
Organic and volatile matter	4.479		
Lime (CaO)	*2.703*		
Potash (K_2O)	*.818*	Other determinations:	
Soda (Na_2O)	.335	*Humus*	*.914*
Magnesia (MgO)	2.326	*Nitrogen*	*.058*
Manganese oxide (Mn_3O_4)	.037	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.207*	Total soluble salts	.107
Sulphuric acid (as SO_3)	.047	Sodium carbonate	.027
Carbonic acid (as CO_2)	.885	Sodium sulphate	.014
Chlorine	.009	Sodium chloride	.016
Net total	100.091		

Soil No. 7 is from a tract, formerly famous for its grain crops, situated in the old wash of Cave Creek, which has now been intercepted by the Arizona canal. It is rich in potash, lime, and phosphoric acid, and contains more than the usual amount of humus and nitrogen In these respects it bears a close resemblance to No. 2 from the Baxter ranch, and No. 5 from the Improvement Company's section near Glendale. It has the advantage of these soils, however, in being of loose texture and more permeable to water, and at the same time has a great water-holding power. its superior physical condition may in part be due to the presence of less alkaline salts, but is probably chiefly due to a fortunate combination of the different physical grades of soil particles

Soil No 19, virgin desert, south of Mesa City, Sec 84, T. 1 N, R 5 E

Gravel, coarser than 5 m m	67%	Water tests	
Fine earth	99 33	Moisture in air-dry soil	3 435%
In fine earth, water free	— —	Hygroscopic moisture	7 889
Insoluble matter—sand etc	54.895	Drainage test	17 c c
Soluble silica—from clay "	19.590	Capillary water test	31h 29m
Alumina (Al_2O_3)" " "	9 619	Maximum water capacity	41 89%
Iron oxide (Fe_2O_3)" " "	5 228	Minimum " "	16 82
Organic and volatile matter	4 042		
Lime (CaO)	*1240*		
Potash (K_2O)	*1 959*	Other determinations	
Soda (Na_2O)	447	*Humus*	*831*
Magnesia (MgO)	2.102	*Nitrogen*	*042*
Manganese oxide (Mn_3O_4)	045	Alkaline salts	
Phosphoric acid (as P 265)	*.227*	Total soluble salts	.129
Sulphuric acid (as SO_3)	052	Sodium carbonate	.033
Carbonic acid (as CO_2)	326	Sodium sulphate	.029
Chlorine	014	Sodium chloride	.023
Net total	99 783		

Soil No. 19, representing a large tract lying under the Highland canal, is exceedingly rich in potash, contains an abundance of phosphoric acid and a fair amount of lime, but is somewhat low in nitrogen. The large amount of soluble silica and alumina, the low drainage test, and the very slow capillary movement, tally with the somewhat heavy character of this soil. It is probably excellent alfalfa land, but would, in all likelihood, prove of questionable value for orchards.

Soil No 8, Fowler Bros , Sec 6, T 1 N , R. 2 E

Gravel, coarser than 5 m m	87%	Water tests	
Fine earth	99 13	Moisture in air dry soil	3 297%
In fine earth, water-free		Hygroscopic moisture	9 566
Insoluble matter—sand etc	49 710	Drainage test	9 c c
Soluble silica—from clay "	21 065	Capillary water test	23h 29m
Alumina (Al_2O_3) " " "	9 183	Maximum water capacity	51 83°
Iron oxide (Fe_2O_3) " " "	6 036	Minimum " "	22 78
Organic and volatile matter	6 509		
Lime (CaO)	*2 419*		
Potash (K_2O)	*970*	Other determinations	
Soda (Na_2O)	448	*Humus*	*1 684*
Magnesia (MgO)	2 541	*Nitrogen*	*115*
Manganese oxide (Mn_3O_4)	042	Alkaline salts	
Phosphoric acid (as P_2O_5)	*210*	Total soluble salts	153
Sulphuric acid (as SO_3)	079	Sodium carbonate	052
Carbonic acid (as CO_2)	915	Sodium sulphate	045
Chlorine	010	Sodium chloride	017
Net total	100 135		

Soil No 8 is very heavy, containing a large proportion of clay and rich in all the essential plant foods, as well as in humus. The latter constituent is more abundant, possibly, because alfalfa had been grown on this ground, and the decay of its roots may have added to the humus. Not only this, but alfalfa, as mentioned before, is one of those plants whose roots are instrumental in fixing the nitrogen of the air in the soil in available form, and which also, penetrating deeply into the subsoil, bring potash and phosphoric acid to the surface and leave them there when they decay These facts probably account in part for the richness of this soil in the various essentials

Physically, this soil is impervious to water and consequently difficult to irrigate. When once saturated, however, it holds an enormous amount of moisture and the capillary test indicates slow evaporation and excellent drouth-resisting power under proper tillage

It is good alfalfa and truck land under our conditions, but is hardly suitable for vines or trees.

Soil No. 16 was taken from a very alkaline locality one mile south of Tempe, where no vegetation grew but a variety of Atriplex and a few other hardy plants. It is distinguished by its enormous percentage of soluble salts and by its behavior with water. It is almost impervious to water by the drainage test and it took no less than 7 days for water to rise 6 inches by capillary action. The hygroscopic moisture taken up by this soil in a damp atmosphere is also very large, being partly due to the fact that the common salt in the alkali attracts moisture. When the alkaline salts were leached out of a portion, its hygroscopic moisture fell from 18.94 per cent to 9.05 per cent, although the drainage and capillary water tests were not much affected. This power of alkali to retain moisture would be an advantage in arid regions if it were not for the injurious nature of the salts themselves.

This soil is rich in all the more important elements of fertility, but the tract which it represents will have to be underdrained before it can be used for ordinary crops.

Soil No. 16, Sec. 22, T. 1 N., R. 4 E., south of Tempe, from very alkaline ground.

Gravel, coarser than .5 m.m.	2.29%	Water tests:	
Fine earth	97.71	Moisture in air-dry soil	3.567%
In fine earth, water-free:		Hygroscopic moisture	18.94
Insoluble matter—sand, etc.	48.290	Drainage test	2.4c.c.
Soluble silica—from clay "	16.985	Capillary water test	7 days
Alumina (Al_2O_3)" " "	7.362	Maximum water capacity	37.70%
Iron oxide (Fe_2O_3 " " "	4.819	Minimum water capacity	24.87
Organic and volatile matter	5.118		
Lime (CaO)	*5.711*		
Potash (K_2O)	*1.094*	Other determinations:	
Soda (Na_2O)	1.997	*Humus*	*1.083*
Magnesia (MgO)	3.086	*Nitrogen*	*.108*
Manganese oxide (Mn_3O_4)	.035	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.179*	Total soluble salts	4.399
Sulphuric acid (as SO_3)	.319	Sodium carbonate	.052
Carbonic acid (as CO_2)	3.687	Sodium sulphate	.353
Chlorine	1.724	Sodium chloride	2.845
Net total*	100.016		

Soil 18 presents favorable figures as to chemical composition and its behavior with water. Though fairly porous to water it is not a drouthy soil under proper cultivation, as is shown by the medium rate of capillary movement and a good water capacity.

It is preceptibly alkaline, though not excessively so. The percentage of nitrogen inclines to be low.

Soil No. 18, Canaigre plantation, south-west of Tempe, south line of Sec. 30, T. 1 N., R. 4 E.

Gravel, coarser than .5 m.m.	14.34%	Water tests:	
Fine earth	85.66	Moisture in air-dry soil	2.597%
In fine earth, water-free:	———	Hygroscopic moisture	7.30
Insoluble matter—sand etc.	61.570	Drainage test	64 c. c.
Soluble silica—from clay "	15.765	Capillary water test	5h–48m
Alumina (Al_2O_3) " "	6.794	Maximum water capacity	38.16%
Iron oxide (Fe_2O_3) " "	4.503	Minimum " "	12.87
Organic and volatile matter	4.107		
Lime (CaO)	*2.611*		
Potash (K_2O)	*1.045*	Other determinations:	
Soda (Na_2O)	.312	*Humus*	*.810*
Magnesia (MgO)	2.013	*Nitrogen*	*.056*
Manganese oxide (Mn_3O_4)	.052	Alkaline salts:	
Phosphoric acid (as P_2O_5)	.147	Total soluble salts	.259
Sulphuric acid (as SO_3)	.080	Sodium carbonate	.064
Carbonic acid (as CO_2)	1.376	Sodium sulphate	.029
Chlorine	.026	Sodium chloride	.043
Net total	100.395		

Soils 15, 12 and 18 represent the wash of the peculiar low range of hills nearly east of Phoenix, particularly of the small mountain sometimes known as Victoria butte. Sample 12 represents the soil of an orange orchard situated on the north slope of this mountain, which for some unknown reason did not

Soil No. 15, virgin desert between Tempe and Phoenix, Sec. 6, T. 1 N., E. 4 E.

Gravel, coarser than .5 m.m.	27.41%	Water tests:	
Fine earth	72.59	Moisture in air-dry soil	1.490%
In fine earth, water-free:		Hygroscopic moisture	3.655
Insoluble matter — sand etc.	71.663	Drainage test	363 c.c,
Soluble silica — from clay "	9.521	Capillary water test	47m.
Alumina (Al_2O_3) " "	4.208	Maximum water capacity	34.694
Iron oxide (Fe_2O_3) " "	4.024	Minimum " "	13.77
Organic and volatile matter	2.424		
Lime (CaO)	*3.513*		
Potash (K_2O)	*.683*	Other determinations:	
Soda (Na_2O)	.260	*Humus*	.93*
Magnesia (MgO)	1.466	*Nitrogen*	*.043*
Manganese oxide (Mn_3O_4)	.092	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.149*	Total soluble salts	.160
Sulphuric acid (as SO_3)	.030	Sodium carbonate	.060
Carbonic acid (as CO_2)	2.053	Sodium sulphate	.021
Chlorine	.011	Sodium chloride	.018
Net total	100.096		

prosper as well as the orchard on the opposing slope of the Camelback mountain, half a mile distant, and represented by sample 11. The samples all have sufficient potash, and No. 15 shows plenty of phosphoric acid, but 12 and 13 are low in this constituent. The nitrogen percentages run rather low. The percent-

Soil No. 12, Sec. 28, T. 2 N., R. 4 E., south of Ariz. Imp. Co.'s orange orchard where trees do not prosper best.

Gravel, coarser than .5 m.m.	18.29%	Water tests:	
Fine earth	81.71	Moisture in air-dry soil	2.307%
In fine earth, water free:		Hygroscopic moisture	6.01
Insoluble matter — sand etc.	66,075	Drainage test	130 c.c.
Soluble silica — from clay "	11.285	Capillary water test	2h-6m
Alumina (Al_2O_3)" " "	5.523	Maximum water capacity	39.90%
Iron oxide (Pe_2O_3)" " "	4.052	Minimum " "	14.00
Organic and volatile matter	4.003		
Lime (CaO)	*4.205*		
Potash (K_2O)	.777	Other determinations:	
Soda (Na_2O)	,270	*Humus*	.662
Magnesia (MgO)	1.564	*Nitrogen*	.055
Manganese oxide (Mn_3O_4)	.039	Alkaline salts:	
Phosphoric acid (as P_2O_5)	.053	Total soluble salts	.106
Sulphuric acid (as SO_3)	.036	Sodium carbonate	.045
Carbonic acid (as CO_2)	2.567	Sodium sulphate	.017
Chlorine	.007	Sodium chloride	.012
Net total	100.454		

Soil No. 13, virgin desert, from north slope of Victoria butte, Sec. 33, T. 2 N., R. 4 E.

Gravel, coarser than .5 m.m.	41.03	Water tests:	
Fine earth	58.97	Moisture in air-dry soil	2.697%
In fine earth, water-free:		Hygroscopic moisture	6.307
Insoluble matter—sand, etc.	67.475	Drainage test	107 c.c.
Soluble silica—from clay "	12.510	Capillary water test	2h-10m
Alumina (Al_2O_3)" " "	5.615	Maximum water capacity	35.58%
Iron oxide (Fe_2O_3 " " "	4.524	Minimum water capacity	12.96
Organic and volatile matter	3.298		
Lime (CaO)	*2.854*		
Potash (K_2O)	.686	Other determinations:	
Soda (Na aO)	.458	*Humus*	.405
Magnesia (MgO)	1.447	*Nitrogen*	.031
Manganese oxide (Mn_3O_4)	.021	Alkaline salts;	
Phosphoric acid (as P_2O_5)	.045	Total soluble salts	.537
Sulphuric acid (as SO_3)	.046	Sodium carbonate	.059
Carbonic acid (as CO_2)	1.396	Sodium sulphate	.038
Chlorine	.145	Sodium chloride	.239
Net total	100.487		

age of lime, however, is in each case higher than the average and this fact suggests the existence of unusual amounts of this material in the rocks of this range, and of more than ordinary deposits of calichi, or limy hardpan, below the surface. These deposits, so well known throughout Southern Arizona, occur at depths varying from a few inches to several feet and are situated at the point to which the scant rains of the semi-arid regions carry the lime, dissolved in the carbon dioxide of the rainwater. The lime thus carried down remains as a layer of impure limestone at varying depths. In the case of soil 13 the calichi layer was about eight inches below the surface. In the orchard represented by soil 12 it was encountered at greater depth. It is very generally present, being often so near the surface and in such amount as to prevent the development of tree roots. Especially in the case of orchards, the amount and depth of this calichi must be considered in connection with the examination of the surface soil.

Soil No. 20, from W. J. LeBaron's ranch, 21 miles N. E. of Casa Grande, where fruit trees die of root disease.

Gravel, coarser than .5 m.m.	22.05%	Water tests:	
Fine earth	77.95	Moisture in air-dry soil	1.866%
In fine earth, water-free:		Hygroscopic moisture	4.08
Insoluble matter—sand etc.	81.597	Drainage test	842 c.c
Soluble silica—from clay "	7.703	Capillary water test	35m
Alumina (Al_2O_3) " " "	3.781	Maximum water capacity	30.67%
Iron oxide (Fe_2O_3) " " "	2.581	Minimum " "	6.97
Organic and volatile matter	1.959		
Lime (CaO)	*.579*		
Potash (K_2O)	.534	Other determinations:	
Soda (Na_2O)	.254	*Humus*	.762
Magnesia (MgO)	.775	*Nitrogen*	*.038*
Manganese oxide (Mn_3O_4)	.060	Alkaline salts:	
Phosphoric acid (as P_2O_5)	*.031*	Total soluble salts	.163
Sulphuric acid (as SO_3)	.038	Sodium carbonate	.033
Carbonic acid (as CO_2)	.108	Sodium sulphate	.018
Chlorine	.023	Sodium chloride	.038
Net total	100.018		

Soil 20 is of special interest because of the death of fruit trees growing in it. On inspection the roots were found to be affected with a fungous disease probably induced by a feeble condition of the tree. An examination of the soil suggests possible

causes of such a condition. Chemically, there is a deficiency of phosphoric acid and nitrogen in particular, with but moderate amounts of lime and potash.

The mechanical character presents more serious objections. The water tests show that it has low water capacity, and drains with excessive rapidity. Moreover, this soil, undisturbed in the field, or when compressed in the hand, is very dense and lifeless. A physical analysis was made in order to explain this character, if possible, with the following results;

Mechanical analysis of soil No. 20.

Water-free.	*per ct*
Coarser portion, sands, 5 to .05 m m. diam	77.27
Medium " silts, .05 to .005 m m "	7.72
Fine " clay, finer than 005 m m	11.79
Organic and volatile matter	2.35
Total	99.13

It here appears that this soil is more than three-fourths composed of coarse material, with one-fifth of silt and fine clay, and very little organic matter. In other words, it has a bricks-and-mortar composition which, in the absence of organic matter, may easily account for its tendency to form dense, coherent masses.

Undoubtedly soil 20 would be greatly benefited by growing alfalfa upon it. The strong roots of this plant would not only open up the packed sub-soil, but would bring potash, phosphoric acid, and other constituents to the surface. By using the plant for green manuring, large amounts of humus and nitrogen may also be added.

Hardpan was not encountered up to a depth of four feet.

Soil $1, which is stated to represent the wash of the Colorado river, is very rich in lime in the form of carbonate, and is well supplied with potash, phosphoric acid and nitrogen. The alkaline salts, though "white" in character, are high, and probably will need to be removed by drainage.

The water tests indicate a soil of excellent physical character, allowing rather slow passage to water but of good drouth resisting powers.

Soil 21, from a valley of the Colorado River near Needles, Cal
(Partial analysis.)

Gravel, coarser than 5 m m	.41	Water tests	
Fine earth	99 59	Moisture in air-dry soil	2.325%
In fine earth, water-free		Hygroscopic moisture	8.350%
Insoluble matter—sand, etc	60 095	Drainage test	26 c.c
Soluble silica — from clay "	11 855	Capillary water test	5h-29m
		Maximum water capacity	43.915%
		Minimum " "	18 915
Organic and volatile matter	2 338		
Lime (CaO)	*6 427*		
Potash (K_2O)	*928*	Other determinations	
		Humus	884
		Nitrogen	075
		Alkaline salts	
Phosphoric acid (as P_2O_5)	*185*	Total soluble salts	.821%
		Sodium carbonate	063
Carbonic acid (as CO_2)	5 060	Sodium sulphate	481
		Sodium chloride	.229

GENERAL REMARKS ON SALT RIVER VALLEY.

In order to perceive more readily the prevailing facts concerning the soils examined, most of the average results for the valley are stated in the table on the next page.

Considering the more critical plant foods in order, it is observed first, that *lime* averages no less than 2.372 per cent for the twenty samples from the valley, and is mostly in the form of the carbonate, which is so useful for the flocculation of clay soils and their consequent improvement in tilth. In arid regions this is a fortunate compensation for the small amounts of humus which prevail. In humid regions the situation is reversed. Lime being present in but small amounts in such soils, tilth is more largely influenced by humus, which is found most abundantly in damp, cool situations.

This abundance of lime is characteristic of arid regions and is one reason for the fertility of these soils under irrigation, since this substance not only improves physical condition, but preserves humus, and renders phosphoric acid and potash more available to vegetation.

Potash is abundant everywhere, being deficient in not a single case and showing an average of ,821 per cent, or more than

Table of average results.

In fine earth, water-free·			
Insoluble matter—sand etc	64.575	%	
Soluble silica—from clay **	13.781		
Alumina (Al_2O_3) " " *	6.433		
Iron oxide (Fe_2O_3) " " "	4.922		
Organic and volatile matter	3.569		
Lime (CaO)	*2.372*		
Potash (K_2O)	*821*	*Humus*†	*.650%*
Soda (Na_2O)	.425	*Nitrogen*‡	*.045*
Magnesia (MgO)	1835	Alkaline salts:	
Manganese oxide (Mn_3O_4)	.055	Total soluble salts	.167
Phosphoric acid (as P_2O_5)	*.130*	Sodium carbonate	.044
Sulphuric acid (as SO_3)	059	Sodium sulphate	.030
Carbonic acid (as CO_2)*	1 025	Sodium chloride	.041
Chlorine	.110		
Net total	100 112		

*This amount of carbonic acid calculates to 2 33 per cent of carbonate of lime
†Excluding soil No 8
‡Excluding soil No 16.

twice what is usually considered essential to fertility. The feldspars which are found in the granites of this region are rich in potash, and by their weathering and decomposition contribute this element of fertility abundantly to the tilth of the valley.

Phosphoric add makes a fairly satisfactory showing. The average of 0 13 per cent is somewhat in excess of the necessary amount, and, as stated before, the large percentage of lime associated with it should tend to make it more available. In particular cases these soils are undoubtedly deficient in this element of fertility. Such for instance, are samples Nos. 12, 11, 20, 33, 14, and 1, and it may be something more than a coincidence that Nos. 1, 12, 13 and 20 are from localities where fruit trees are in unhealthy condition. These soils would quite probably profit by the addition of fertilizers containing phosphoric acid. Commercial phosphates are beyond the reach of most farmers of this region but phosphoric acid may be supplied, with other needed materials, in barnyard manure. Bat guano also contains much phosphoric acid, our samples showing from 3.36 to 6.91 per cent. It is possible also that the local supply of bones could be ground and treated profitably for this purpose, but some machinery and considerable skill are needed for this work.

Zeolites It will be noticed in the table that the soluble silica averages more than twice as much as the alumina (13.781%

to 6.433%.) This excess of silica suggests the presence of zeolites, since, as Dr. Hilgard points out, the ratio of silica to alumina in pure clay is only about as 46 to 40. The existence of zeolites is further indicated by the fact that lime, magnesia, potash and soda are far in excess of the amounts necessary to combine with the carbonic, sulphuric, and phosphoric acids present.

The importance of zeolites, as emphasized by Dr. Hilgard, consists in the fact that they are repositories of plant foods, from which, by slow decomposition, these compounds are gradually given up as needed. The existence of zeolites in large amount therefore augurs well for the wearing qualities of soils containing them.

Alkaline salts are not as a rule present in unmanageable amounts, though in connection with heavy soils they occasionally make a good deal of trouble. Just south and south-west of Tempe is a tract of low, heavy land containing an excessive amount of alkaline salts. In its virgin state this tract, which is represented by sample 16, supports a bushy growth of Atriplex and a few hardy weeds, but has not been reclaimed for agricultural purposes. An examination of the analysis of soil 16 will show that the alkali in this tract, as indeed, nearly everywhere in the valley, is chiefly "white" in character and contains a relatively small proportion of the more injurious sodium carbonate or "black" alkali. Consequently these lands must be reclaimed, not by treatment with gypsum, which is an antidote for black alkali, but by drainage, and the entire removal of the objectionable salts. The Australian salt bush, which is not only an excellent forage, but grows readily in excessively alkaline soils and removes large amounts of the injurious salts, may also prove useful in some situations hereabouts.

The effects of Salt River irrigation water upon the alkali of this region has yet to be determined, our data as yet being incomplete in this respect. A composite sample representing the supply for January, 1897, was found to contain 46 4 parts of dissolved salts in 100,000 of water. This amounts to 1264 pounds in an acre foot of water, which, if left behind in the soil would amount to about ,032% of alkaline salts. A cursory examinaton shows these dissolved salts to consist of nearly half of sodium chloride. Further information is needed upon the composition and probable effect of irrigation waters upon soils in this region

The silt brought down with the water has a manifest effect upon the physical nature of our irrigated soils, but we have not confirmed the popular notions regarding its fertilizing value by any investigation of its composition.

THE CHIEF DEFICIENCIES OF OUR DESERT SOILS AND SUGGESTIONS FOB OVERCOMING THEM.

Nitrogen is probably seriously lacking in most of the soils of the valley. The average of .045 per cent is low and includes amounts running from ,029 per cent in soil 4, to .108 per cent in soil 16. The smallness of these figures may be seen by com parison with the average amount of nitrogen (humic nitrogen only) in 18 and soils, stated by Dr. Hilgard at .101 per cent, or more than twice as much as the Arizona average.

That these soils are nitrogen-hungry is indicated also by a leaf curl disease which has been noticed among the peaches and apricots on the Phoenix sub-station by Professor Toumey, who attributes the trouble to a weakened condition resulting from a lack of soil nitrogen.

The problem of supplying deficient nitrogen is, therefore, a most serious one, inasmuch as nitrogen is the most costly plant-food sold in commercial fertilizers. Fortunately, however, a cheap method exists for accomplishing this work, namely, by cultivating leguminous crops upon the land, such aa alfalfa, crimson clover, sour clover, cow-peas, vetches, beans, peas, or other members of this class of plants, according to circumstances of climate, water, and soil. These plants, as mentioned before, maintain upon their roots colonies of peculiar bacteria, appearing as small lumps or tubercles, which have power to convert nitrogen from the air into the nitric form available to vegetation. Upon the decay of the whole plant, which may be plowed under as green manuring, or of the roots and stubble, if the crop is harvested, the nitrogen contained, in combination with humus, remains behind and is available to other crops which have not the power of deriving their nitrogen supply from the air.

Doubts have been expressed, when alfalfa is out for hay, that the nitrogen returned to the soil by decaying roots and stubble, makes up for that which is taken away from the soil during the growth of the plant; for alfalfa is known to feed upon soil nitrogen as well as that indirectly obtained from the air. Of course this return will be made, with interest, when the whole crop is plowed under and the same will be true when it is pastured, the nitrogen being then returned in the excrements of the animals on the ground.

In Salt River Valley most alfalfa fields have been used both for hay cutting and pasture. In order, therefore, to determine the effect of the prevailing management of this crop upon soil nitrogen, samples were taken from nine fields in the valley which had formerly been in alfalfa from 5 to 15 years. These samples gave .052, .073, .060, .056, .090, .068, .097, .095 and .115 per cent respectively, or an average of .078 per cent as compared with the average of .045 per cent for the virgin soils of the valley, an in* crease of about two-thirds. It is noteworthy that of the percent* ages of nitrogen in alfalfa ground, not one falls below the average of that in virgin soils, while in but one case, No, 16, does the nitrogen of virgin soils exceed the average in alfalfa ground. The effect of alfalfa upon soil nitrogen in ordinary practice is therefore sharply marked so far as our observations go.

The examinations made in the laboratory thus confirm, in part, the experience of the farmers of Southern Arizona as to the most profitable method of handling our desert soils. This consists simply in growing alfalfa upon the ground before attempting other crops. It has repeatedly been stated to the writer by residents of Salt River Valley that orchards, wheat, and various other crops were conspicuously thriftier on old alfalfa ground than on adjacent virgin tracts. It was also observed in 1897, during the work on sugar beets, that the best beets came from alfalfa ground, being richest in sugar and of greatest purity.

ALFALFA IMPROVES THE PHYSICAL CONDITION OF THE SOIL.

The beneficial effects of alfalfa, however, are due not only to the increase of nitrogen in the soil, but to a great improvement in its physical condition. The compact character of our desert soils is forbiddingly evident to most observers, especially those accustomed to the loose virgin tilth prevalent in humid climates. This denseness and solidity, so necessary to overcome, is due to various causes.

In the first place, alkaline salts, especially sodium carbonate, destroy the flocculated or grainy character of soils, which is chiefly caused by lime. Now, although lime is abundant in this region, and the alkali very mild in character, the sodium carbonate present, averaging .044 per cent for the valley, undoubtedly contributes materially to the undesirable physical condition of our virgin desert soils. Again, the tremendous though not very frequent down-pours of rain which occur throughout Southern Arizona, descending upon the bare and nearly unprotected desert, undoubtedly puddle the soil and pack it into an increasingly solid mass. Finally, the intense and prolonged heat of our summers favors the slow combustion of what little organic matter the soil contains and thus leaves it nearly without one very efficient cause of good tilth.

Although the humus of arid regions is generally low, it seems unusually so in Southern Arizona. Dr. Hilgard states the average for 313 arid soils from California, Washington and Montana at 1.84 per cent, while that from 19 samples of Salt River Valley is only .65 per cent, or about one-third. This unusual deficiency, together with the peculiar value of humus in an arid region, through its water holding and tilth producing powers, makes the problem of increasing its amount a very important one.

Alfalfa and other green manuring crops, and barnyard manure are the chief means at hand for effecting this addition. Alfalfa is particularly mentioned because it is the best known crop for our conditions of soil and climate, but other forage plants are attracting notice. Among these is sour clover, (Melilotus Indica) which thrives vigorously here. The practice of plowing barley nnder for green manuring, indulged in by some farmers, is of limited value for the reason that barley does not assimilate atmospheric nitrogen and add it to the soil after the manner of clovers and other legumes.

Leguminous crops should therefore be chosen for green manuring in this region, and the work of discovering new plants and improving the methods of handling those already known for this purpose, is a most important branch of agricultural inquiry with us at the present time.

Alfalfa in particular, however, improves the condition of our soils in yet another way. The strong, numerous roots of this plant penetrate to great depths, (about twelve feet in dry soil was observed by Professor Headden in Colorado) and in so doing open up the soil to air and water and prepare the way for the less vigorous roots of other plants. This view of the usefulness of alfalfa is supported by the observation that there are other strong rooted plants, not leguminous in character, and which consequently can not add nitrogen to the soil, whose good effects upon subsequent crops are noticeable The spiny aster, one of our rankest weeds, and sorghum, which taxes soil severely for plant foods, have both been observed to benefit subsequent crops, for no other apparent reason than the loosening action of their roots upon the dense virgin earth.

A COMPARISON.

Finally, although comparisons are said to be odious, they are apt to be instructive, and it may not be amiss to compare the soils of Salt River Valley with those of other arid regions. The following table, compiled from Dr. Hilgard's figures and those of this bulletin, effect this comparison,

Comparison by states of arid region soils.

	California	*Washington*	*Montana*	*Arizona*
No. of soils averaged	198	76	39	20
Insoluble residue	67,882	75,021	66.141	64.575
Soluble silica	8.960	3.673	6.235	13.781
Potash	.644	,777	1.005	.821
Soda	.277	.249	.226	.425
Lime	1.075	1.378	2.483	2.372
Magnesia	1.488	1.171	1.494	1,835
Manganese oxide	.062	.049	.057	.055
Iron oxide	6.303	$.530	4,459	4.922
Alumina	8.721	6.063	7,145	6.433
Phosphoric acid	,083	.173	,178	.130
Sulphuric acid	.048	.028	.029	.059
Carbonic acid	1.148*	.403	2.398	1,025
Water and organic matter	4.396	5.226	7.133	3.569
Chlorine				.110
Totals	99.939	99.741		100.112
Humus	1.040	1.155	3.321	.650

*Not Included in total.

It appears from this table that in potash, lime, and phosphoric acid, Arizona occupies an intermediate position, being richer, usually, in these constituents than the average California and Washington soils, but poorer than those of Montana.

It is noteworthy that in Arizona the amount of soluble silica is remarkably large, being even more than twice the alumina present, while in California and Montana these constituents are about equal, and in Washington the soluble silica is much less in quantity than the alumina. This points to the peculiarly zeolitic character of the soils of Arizona, and leads to favorable inferences regarding their wearing qualities, at least so far as mineral-ash plant foods are concerned.

Humus is conspicuously deficient in Salt River Valley. Montana soils contain five times as much humus as those of Arizona. This is doubtless largely due to the temperature, the warmer climate of Arizona favoring the slow combustion of organic matter.

SUMMARY OF RESULTS.

1. The soils of Salt River Valley, generally speaking, are amply supplied with the more essential mineral-ash plant foods, including lime, potash, and phosphoric acid.

2. Nitrogen and humus are undoubtedly deficient in quantity, and the addition of these soil ingredients is desirable, perhaps imperative

3. Alkaline salts are not prevalent in excessive amount except in occasional localities of limited area. The alkali is very "white" in character and, consequently, its injurious effects are minimum.

4. Probably the most serious difficulty with our virgin soils is a physical one. Their dense, compact condition must be remedied by suitable methods of culture.

5. The cheapest and best methods of supplying the lack of humus and nitrogen, and of improving the tilth and water holding power of these soils is by growing leguminous crops upon the lands and plowing them under as green manuring. So far as now known, alfalfa and crimson clover are the best of these and their use for this purpose is undoubtedly an essential part of any scheme of crop rotation for this region.