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UNPRODUCTIVE SOILS, THEIR CAUSE AND MANAGEMENT

The soil problems confronting the farmer in semi-arid regions are many and varied. Perhaps the commonest of them is unprofitable production or complete failure of certain crops—in extreme cases of all crops, in spots, strips or even large areas. Such soils, which support little or no vegetation under irrigation, are popularly called "slick," and may be divided into two general classes: Those that are unproductive because of chemical defects, and those that are physically defective. Soils of the latter type generally fail to produce on account of their high content of extremely fine material which withholds relatively large amounts of water from the plant. Moreover, they usually take water very slowly and bake easily, making it almost impossible to obtain and maintain a profitable stand. Chemically defective soils may lack some essential element, but more often excessive amounts of soluble compounds known as "alkali" cause the diminished yields. Alkaline soils that contain sodium carbonate or "black alkali," also allow but slow penetration of water, and where strongly impregnated with black alkali may appear slick and glossy when wet as compared with adjacent sweeter soils. In this case we have the combined effect of both chemical and physical defects. Farmers unfamiliar with arid soils often err in supposing that any unproductive soil requires some kind of fertilizer to bring up its fertility. In humid regions the soil doctor carries a few prescriptions which usually remedy all difficulties. These prescriptions are fertilizer, drainage, aeration, humus, limestone to correct acidity, crop rotation, and more thorough tillage. Some of these are available and potent remedies for certain unfavorable conditions in arid soils; others are not

The purpose of this Timely Hint is to point out the causes of unproductiveness in arid soils rather than to advertise any panacea for their cure, Remedies will be suggested where remedies are known. Whether it be advisable to apply the remedy in any given case must be left to the individual who will be guided by his own experience, and that of his neighbors. As land values increase or water supplies are better developed it may become profitable to correct defective soils that for some years to come had better be left fallow. Small areas in otherwise good farms, especially when conspicuous, may be treated with profit to the land owner even at great cost.

CHEMICALLY DEFECTIVE SOILS

Alkali: Unproductiveness due to alkali is so common in Arizona that soils of this class must be given first place in any general discussion of abnormal soils. Alkali is a defect of arid soils due to soluble salts which will accumulate in any sparingly watered soils until they become harmful to vegetation. Their harmfulness may be the result of physiological action on the plant or of physical effects on the soil itself. The deleterious effects of white alkali are probably almost entirely physiological; but black alkali has the added bad quality of putting the soil in the poorest possible mechanical condition. This will be understood better after we have discussed the physical or mechanical defects of soils. Black alkali and organic matter are believed to lead to the formation of toxic substance in some cases.

In a more or less arbitrary way the limit of tolerance of ordinary crops for the common forms of alkali has been set at one-tenth per cent for black alkali, four-tenths per cent for sodium chloride, and five-tenths for sodium sulphate. Field studies, however, show these limits to be widely variable, for reasons as yet imperfectly understood.

Other forms of alkali, especially magnesium chloride and sodium nitrate, are sometimes encountered. Soils highly impregnated with magnesium chloride appear wet even in the dryest season and samples have been sent in to be examined for oil because of their greasy feel. All forms of alkali manifest themselves most perniciously when they accumulate at the surface, A zone of saline matter or alkaline crust is thus formed through which the plant must grow, and here most species perish.

When the alkali content of the soil is in excess of the limit of tolerance, to any appreciable depth, little can be done to remedy the trouble unless good drainage can be established and sufficient water is available to leach out and carry off the excess of salts. Eventually these conditions must be had to insure continued high productiveness with most soils that even without special care may give good returns for many years. Opportunity to flood such soils with sweet flood waters never should be lost. Moderately alkaline soil, however, may be kept productive much longer, and likewise moderately alkaline irrigating water may be used, by careful methods of culture. Such soils, moreover, are usually supplied abundantly with soluble mineral plant food. In these cases the rise of alkali is to be carefully avoided. Alkali may rise in spots or over the field as a whole. Spots will usually appear where the land has not been well leveled, and on the borders. These higher places act like lamp wicks or blotters, soaking up the salt laden water and concentrating the salt as the water evaporates. Irrigation, being shallow over these raised spots, does not suffice to dissolve and carry the salts back into the deeper soil. In this way alkali slick spots often form in what were once fertile fields. On moderately alkaline soil the alkali may be kept distributed by deep plowing and occasional deep rather than frequent shallow irrigation. Cultivation after irrigation to prevent surface evaporation is also effective, especially where only a scanty supply of rather salty water is available. Where once the alkali becomes troublesome and leaching is impossible some relief is afforded by allowing a surface crust to form which may be scraped off or thrown on the border. Such relief is temporary and expensive and should not be considered for large areas. Alkali resistant crops such as sorghum or sugar beets may be grown and removed. These carry off a part of the alkali,

Black Alkali: Black alkali exists in two forms: Sodium carbonate, familiar to all as sal soda or washing soda, and sodium bicarbonate or baking soda. The bicarbonate is the least harmful of the two; but one may change into the other under varying conditions of heat, aeration, and carbonation which are not well understood in field practice. Black alkali is harmful in much smaller amounts than white alkali, but such crops as alfalfa, when once established, often do well in rather strongly black alkaline soil. This type of alkali deflocculates the clay and renders the soil more or less impervious to irrigating water. It is also leached from the soil with extreme difficulty. Gypsum or sulphate of lime acts as a chemical antidote to black alkali and at the same time flocculates the clay and restores the soil to its normal physical condition. Sulphate of soda resulting from the reaction is less harmful to plants, and more easily leached from the soil. About twice as much gypsum should be applied as the soil contains black alkali in the upper two or three feet. This may be prohibitive financially on large tracts, but will often aid in getting a stand on small areas in otherwise valuable fields. In some parts of Arizona gypsum is available to farmers for the hauling, which may cost one or two dollars a ton. Where shipping facilities are at hand in the gypsum fields as is the case at Douglas, Arizona, it may be purchased at from $1.25 to $1.50 a ton f. o. b. the cars. Recently good gypsum has been made available in Salt River Valley.

Recent investigations under controlled conditions in the laboratory indicate that "calcium sulphate (gypsum) has no effect in preventing the formation of sodium bicarbonate when sodium sulphate, or a mixture containing sodium sulphate, reacts with calcium carbonate"; and the inference is drawn that "field applications of gypsum will probably have no effect in overcoming black alkali if the soil already contains soluble sulphate in appreciable amounts, or the irrigating water contains these salts." (Breazeale, Journal Agr. Research, Volume 10, No. 11). It is stated, however, that a relatively small amount of calcium nitrate or calcium chloride in this reaction impedes and finally prevents the formation of sodium bicarbonate. This may account for the fact that the continued application for many years of Tucson City water, which carries relatively large amounts of sodium sulphate and chloride and has high temporary and permanent hardness (calcium and magnesium salts), to the shallow, highly calcareous soils which cover a dense calcareous hardpan (caliche) on city lawns has never been known to result in the formation of black alkali. Also the strongly black alkaline soil from the University farm, which is physically classified as a very fine sand or sandy loam, changes its character immediately on the application of sufficient gypsum. The untreated soil takes water slowly and the scanty percolate is dark coffee colored. After the soil has been mixed with gypsum, water percolates readily and the percolate is light straw in color. Since all Arizona alkaline soils, and most irrigating waters contain large amounts of chlorides in association with sulphates, we may expect good field results with gypsum.

In practice both stable manure and green manures have proven valuable on moderately black alkaline land. In the long run the use of nitrogenous fertilizers and leguminous green manures will probably be found to intensify black alkaline conditions.

Soils that are excessively alkaline with either black or white alkali, and not subject to reclamation by drainage and leaching, should be left uncultivated or given to some uncultivated alkali resistant growth, such as Bermuda grass, saltbush, cottonwood and mesquite for fire wood, or tamarisks. Asparagus also may be grown on somewhat salty land, and date palms thrive on strongly alkaline soils where climatic conditions are favorable. It often happens that unsightly alkali sloughs occur in conspicuous places on valuable ranches. These justify relatively heavy expenditures for drainage or chemical treatment; but when such remedies seem impracticable the unsightly spots may be hidden with native alkali vegetation, or turned into wood lots by planting with cottonwood or tamarisk. Where the climate will permit, date palms will form at least a pleasing screen.

DEFICIENCY OF ESSENTIAL FOOD ELEMENTS

The statement is commonly made that arid soils contain the essential elements for crop production in sufficient amounts and when supplied with water will produce large crops indefinitely. Let us consider the facts for the elements that are frequently deficient,

Potassium is found by analysis to be present in nearly all soils in amounts sufficient to produce maximum crops for centuries. Usually only a small part of it is available at any one time, possibly not over one-quarter per cent of the total amount present, but proper cultural methods suffice to keep available a reasonable supply. Since the relatively large amounts of water soluble salts in arid soils contain some potassium, and this supply is further augmented by that contained in irrigating water, the potash problem has given the agriculturists of the Southwest but little concern. Field plot experiments, however, are lacking. This conclusion is probably correct in the majority of cases, but a few very sandy soils and other soils composed of slightly weathered minerals may be found to produce heavier crops after dressing with potash as well as other fertilizers,

Phosphorus is the one essential plant food that is apt to be depleted in cultivated soils and cannot easily be supplied. An inspection of the available analyses of Arizona soils show their natural phosphorus content to be about equal to that of humid region soils of moderate fertility. This is offset in practice by the fact that crops on irrigated arid soils root deeper and consequently draw on larger volumes of soil. Irrigating waters, however, do not supply phosphorus in important amounts, unless they be laden with silt or organic matter. It is probable that phosphorus is already the limiting factor for productiveness in some of our agricultural soils. Since, under cultivation, this element is destined to become deficient sooner or later, no reasonable opportunity should be missed to keep up the phosphorus supply. All crops that are harvested and removed permanently from the soil draw upon this element. Crop residues of all kinds should, therefore, be returned to the soil, and stable manure that is now wasted should be saved and used. While some farmers always must sell hay and grain, those that sell livestock only and thus return a maximum of fertility to the soil will leave their farms to posterity in the best condition consistent with legitimate use. Alfalfa and green manures cannot improve the fertility of the soil as regards phosphorus.

Nitrogen, barring water, is nearly always the limiting factor, in Arizona, for crops other than legumes. Some heavy black soils that we have examined are fairly well supplied with nitrogen. Soils of this type have produced heavy crops of corn, grains, and sorghums, while adjacent yellow lands fail to produce because of nitrogen starvation. In one instance analysis showed .18 per cent of nitrogen in a black soil and only .03 per cent in an adjoining yellow soil. Although, commercially, nitrogen is the most expensive plant food, the farmer need not fear its exhaustion. By means of legumes used as green manures it can be restored to the soil and the nitrogen fertility maintained. Green manures and their use is fully discussed in Timely Hints No. 119 of the Arizona Agricultural Experiment Station.

Carbonate of lime is seldom deficient in Arizona soils, which are usually richly calcareous and vary in content from those containing a few tenths of one per cent to soft white soils, (usually subsoils) that approach caliche in composition. Caliche, itself, is unproductive with crops that are not lime sensitive, merely because it does not allow sufficient water penetration. It is more abundantly supplied with mineral plant food than the average soil of the region in which it occurs. A few soils, however, are deficient in carbonate of lime and some show positive acidity by certain tests. These are coarse soils from higher altitudes that have been formed by disintegration of rocks poor in lime, and occasionally fine grained soils from irrigated regions. Some of the latter were probably under irrigation in prehistoric times and the natural lime supply was leached out. A fair supply of lime is essential for the successful production of alfalfa and some legumes.

PHYSICALLY DEFECTIVE SOILS

The specific physical defects of certain arid soils will be readily understood if we first get a clear idea of the mechanical composition of soil and Its bearing on the relation of the soil water to the plant. Soils are composed normally of a mixture of various sized sand grains, silt, and clay, together with more or less exceedingly finely divided material known as colloids. Colloids may be either mineral or organic and are so finely divided that they remain permanently suspended in water and cannot be detected even with the microscope. They appear to be dissolved, but are only suspended, as in the case of white of egg or glue stirred up with water. All these soil constituents have the property of condensing water on their surface and holding it tenaceously. The surface area of the finest material, especially of the colloid, is so great in proportion to that of the coarser constituents that the latter becomes almost negligible as far as water retaining capacity is concerned. The result is that nearly all the water in a coarse textured, sandy soil is available for plant growth; but in a fine textured clay soil as much as 15 per cent of its own weight of water may be retained in such intimate contact with the internal surfaces of the soil that it is useless to plants; consequently, crops may be living on a rather dry sandy soil, but may be drought stricken on apparently moister heavy adobe.

Rain and irrigating waters readily penetrate into loose open soils but run off from tight fine grained soils. The structure of fine textured soils may be changed materially by causing numerous fine particles, especially colloids, to combine and act like larger grains, giving the soil a granulated or crumb-like character. This process is known as flocculation and may be promoted by increasing the humus content of the soil or by the addition of caustic lime. The reverse effect is caused by black alkali. Carbonate of lime without humus seems to have less value in promoting granulation than is usually attributed to it, since heavy adobes are often calcareous.

Excessively sandy soils: Small areas of fine sand sometimes occur on good farms, especially where sandy subsoils are uncovered in leveling the land for irrigation. Such soils are usually poorly supplied with plant food and take large amounts of water on account of their loose structure. Muddy irrigating water will, in time, correct the mechanical defects of these soils and also add much plant food. Humus also will render them less pervious and may be supplied by plowing under stable manure or green manure crops. In some extreme cases artificial fertilizer may prove profitable on these soils.

Another type of sandy soil sometimes occurring in gardens and lawns in mining towns is composed largely of imperfectly weathered rock meal usually devoid of carbonate of lime and may show acidity by certain soil acidity tests. Frequently these soils contain large amounts of black magnetite sand which may be separated by stirring them with water, the heavy magnetite settling to the bottom. When these soils are made up of tailings and mining detritus they may contain copper in injurious amounts. Clay, when available, may be applied to these small areas with benefit to cement the rock meal Into a real soil. Available plant food and humus should be supplied in the form of manure or other organic waste. Moderate amounts of air slaked lime, ground limestone, old plaster, or similar material will correct some of the deficiencies of these soils.

Tight silty soils: A common fault with certain Arizona soils Is their tendency to run together when wet and to bake hard on drying.

Specimens of these soils when dry have much the structure of flour or ashes. Their color is yellow to light gray. Under the microscope they are found to be made up of grains of nearly uniform size, mostly silt and very fine sand. Their poor physical character seems to be due in large part to the absence of the coarser soil particles. They also contain considerable exceedingly fine clay and colloidal mineral matter in a highly deflocculated state, as shown by the fact that puddles left on these soils after rains remain turbid for several days. In some instances the deflocculation of these soils may be intensified by a small amount of black alkali. They usually contain an abundance of carbonate of lime. Soils of this type take water with difficulty especially after the first irrigation. Subsoiling gives only temporary relief. These soils would be improved by humus, but humus is exceedingly difficult to maintain in a hot arid country. In some instances rather coarse sand may be found underlying these cementing soils at a depth of two or two and one-half feet. When these conditions are found dynamiting to blow veins of sand up through the silty soil and thus obtain better water penetration should prove successful. If the subsoils can be kept wet as a result of this treatment, root penetration will be encouraged and eventually a better physical condition will be established. The experience of farmers in handling these soils has not been very satisfactory, and it is questionable whether the treatment of large areas would be profitable.

Another type of soil somewhat similar in character is found in the barren painted desert of the northern parts of the State where large areas are entirely devoid of vegetation. Chemically these soils contain moderate amounts of black alkali, but the samples we have examined were free from poisonous heavy metals which were supposed by some to be the cause of the barrenness of these soils. Physically they are composed of uniformly very finely textured material entirely deflocculated. This renders them impervious so that practically all of the scant rainfall runs off. The amount of water necessary to support vegetation on these soils is probably high as might be inferred from their fine texture. Any seeds that might find their way into the region and germinate would quickly perish, consequently, the region is barren.

Many mesa soils of gravelly loam show a tendency to run together when wet and bake. They are deflocculated, although rarely black alkaline, and usually very deficient in humus. Carbonate of lime is generally present in considerable amounts. These soils take water fairly well in their virgin condition and produce good crops. When the soils are first stirred by cultivation the crop is often reduced one-half. The explanation seems to be that plowing breaks up the natural openings left in the soil by plant roots and insects, the soil then running together into a dense impervious mass when irrigated. Careful handling with liberal use of green manure to bring up the humus should eventually restore these soils to their virgin tilth.

Adobe and heavy clay soils: Several types of heavy hard soils are found in Arizona and are probably the strongest soils in the State with regard to plant food. The Salt River adobe is perhaps the best known of these. This is a fine textured soil occurring near the rivers. Soils of this type are difficult to work because of their great plasticity and cohesion. When cultivated at the right moisture content they often work into a fairly fine seed bed, but the limits of moisture between which they can be worked successfully are narrow. Dry adobe tends to break into sharply angular clods with very little fine loose soil.

Another soil with somewhat similar physical properties is the Maricopa clay loam which occurs in small areas in the Salt River Valley. Manure to bring up the humus content of these soils usually results in some improvement, but cases are known where very large applications of farm manure have not made marked improvement in their physical character. Their refractory properties are due to their high content of deflocculated clay and mineral colloids which are best remedied by the application of slaked lime. While this treatment is too expensive for large areas it is often feasible for small gardens.

Heavy dark colored soils one or two feet in depth are often found in level flat regions where flood water spreads out in broad shallow sheets. These soils are very rich, but take water very slowly when irrigated. They are fairly well supplied with natural humus. One sample of this type contained ,18 per cent of nitrogen while adjacent and underlying yellow soil contained ,03 per cent of nitrogen. These dark soils are better adapted to grain and fine rooted crops than deep rooted crops such as alfalfa. If alfalfa roots be traced in soil of this type they will be found to turn abruptly at a right angle and grow horizontally at about the depth of water penetration. As in the case of other deflocculated clays caustic lime is the most effective remedy. Fine rooted grains and grasses increase the humus and have considerable effect in loosening the soil. Bermuda does well on these soils and improves their mechanical condition. Bermuda sod may be turned in the fall and an early crop, such as cantaloupes, produced before the Bermuda again gets possession of the land.

In some sections, notably the Santa Cruz Valley, the soils are highly stratified. These strata have been deposited by flood waters and vary greatly in character. Bands of hard chocolate colored adobe alternate with bands of fine sand and sandy loam. Later erosion has left one or the other type on the surface and often gives a wide variety of soils on a small area. The dark colored bands are very difficult to cultivate, Several inches of water will often dry away without penetrating deeply into these soils. Fortunately such bands are rarely more than a foot thick and where occurring at the surface might be broken and mixed with the sandy subsoil by some form of power plow set very deep. Where covered by several inches of sandy loam, too shallow in itself for profitable cultivation, they may be broken and sand mixed through them by dynamiting. Here again slaked lime will be found the most effective remedy in permanently granulating these soils, since when merely broken up by plowing and cultivation, they return virtually to their former condition the first time they are irrigated. Tongues of similar hard soil sometimes occur on the mesas and mark old, broad, shallow drainage courses.

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