For improving water penetration into some Arizona soils—

Sulfuric Acid

*by S. Miyamoto and J. L. Stroehlein**

Adequate water penetration and drainage are essential for maintaining productive agriculture. In arid and semi-arid regions, this problem is especially important not only to meet high evapotranspiration demands, but also to maintain a favorable salt balance in the plant root zone. Poor water penetration is often a problem with Arizona soils and water. The purpose of this article is to show that locally available sufuric acid can improve water penetration if properly used.

The causes of poor water penetration are many. It may be simply due to poor irrigation techniques, fine soil texture, or unfavorable soil physical conditions such as compaction and puddling. It may be due to excess sodium in soils and/or in irrigation waters. Sulfuric acid has long been recognized as a potentially effective amendment for increasing the rate of water penetration that is restricted by excess sodium.

The effectiveness of sulfuric acid treatments varies depending not only upon the concentration of sodium and calcium in soils and waters, but also upon the types of soils and the rates and methods of acid application. Such technical information has been rather limited or has not been available to users. As a result, acid has been misused in some instances. In this paper, the effectiveness of acid treatment in increasing the rate of water penetration will be discussed for soils and irrigation waters commonly found in southern Arizona. (For the convenience of readers, both metric and conventional units are used.)

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Soil Treatment

Soils having exchangeable sodium percentages (ESP) greater than 15 are commonly called sodium-affected or sodic soils. Sodic soils may appear as small spots in cultivated field or as wide areas such as the Willcox playa. Water penetration into such soils is usually slow because excess sodium disperses soil particles and/or causes swelling of certain types of clay minerals.

Sulfuric acid (and other sulfur compounds) has been used for removing excess sodium from sodic soils. Acid applied to calcareous soils dissolves calcium carbonate (earth lime contained in most Arizona soils) and removes excess sodium when followed by leaching. This flocculates soil particles and improves water penetration. High rates of acid should not be used for noncalcareous soils as it creates undesirable acidic conditions. More details on acid-soil reaction are given in reference 1.

**ESP is a measure of expressing the portion of cation exchange sites occupied by sodium; most soil laboratories run this test upon request.*

The effect of acid treatments varies depending on the exchangeable sodium, acid application methods and rates, and soil-water properties. Table 1 shows some examples. These data were obtained by laboratory penetration tests with concentrated acid sprinkled over calcareous soils. It is evident from these data that the effect of acid progressively increases with increasing ESP. Acid treatment is especially effective in sodium-saturated soils such as the Playa and Stewart soils, although the amounts of acid needed are generally large. Acid treatments of nonsodic soil at high rates decreased the rate of penetration, presumably because of structural disturbance by acid.

In the above examples, acid was sprinkled over soil surfaces in a concentrated form. If the corrosion of irrigation systems is manageable, it may be more convenient to apply acid through leaching or pre-irrigation water. Subsequent laboratory tests have shown that water-applied acid is as effective as soil-applied acid when acid rates are less than about 5 tons/hectare (or 2.25 U.S. tons/acre).

Table 1. Effect of surface-applied sulfuric acid on the depth of water penetration during 5 hours under a 1 cm depth of continuous ponding, laboratory tests.

Soil Samples	*Sampling Locations*	*Exchangeable Sodium*	*H_2SO_4, tons/ha** 0	1	5	10
		%	cm			
Playa clay loam	**Willcox**	**100**	**3**	**7**	**16**	**25**
Stewart silt loam	**Willcox**	**100**	**10**	**16**	**33**	**57**
Gila clay loam	**Ft. Thomas**	**85**	**4**	**11**	**14**	**19**
Pima clay loam	**Safford**	**25**	**13**	**16**	**19**	**21**
Gothard clay loam	**Willcox**	**21**	**23**	**31**	**37**	**40**
Gila clay loam	**Yuma**	**11**	**12**	**15**	**21**	**12**
Elfrida loam	**Kansas Stl.**	**2**	**36**	**41**	**42**	**28**
Cave gravelly loam	**Tucson**	**0.2**	**39**	**42**	**44**	**35**

**To convert to US tons/acre, multiply by 0.45.*

Figure 1. Photo taken at a Willcox sorghum plot; soil-applied acid at a rate of 3 tons/hectare (1.35 US tons/acre) on the left and no acid on the right. Both acid treated and nontreated plots were leached equally with about one foot of water prior to seeding (see Table 3, Collins farm, for soil and water properties).

When acid rates exceed this rate, excessive amounts of carbon dioxide bubble through the wet soils which not only destroy soil aggregates but also build up as a layer in the soil profile and severely impair water penetration. Concentrated acid added to calcareous soils also produces carbon dioxide, but it escapes freely in the absence of free water.

Quality of irrigation water also influences water penetration. When acid is applied to soils in relatively large quantities, water quality makes little difference in water penetration until salts initially present in soils plus those which are produced by acid are leached. Thereafter, the differences in water quality play a key role. These are discussed in the following sections.

Water Treatment

Quality of irrigation water in relation to its effect on soil physical conditions is commonly characterized by the total dissolved salts (TDS)* and the sodium adsorption ratio (SAR)**. As a rule, water penetration decreases as the TDS decreases and the SAR increases. In fine-textured soils, water penetration usually becomes slow when the SAR is greater than about 10 for the majority of irrigation waters. High concentrations of bicarbonate and carbonate also increase SAR as they precipitate calcium.

Application of sulfuric acid in small amounts to high sodium irrigation water is a means of decreasing high SAR by preventing calcium precipitation or by dissolving calcium from calcium carbonate. Acid application rates are ordinarily less than about 90% of equivalent amounts of bicarbonate content when irrigation systems contain concrete ditches and metal pipes. No standard acid rates are yet established for treating irrigation water in sprinkler systems.

**TDS, expressed commonly by electrical conductivity in mmhos/cm or the concentration unit of parts per million.*

***SAR, the relative concentration of sodium to calcium plus magnesium, defined as $Na/\sqrt{Ca + Mg}$, where the concentration of ions are in mmole/liter.*

Table 2. Effect of water-applied sulfuric acid on steady-state infiltration rates.

Water Source	*Well Water*	*Salt River*	*Well Water*	*Rio Grande*
Locations	**Yuma**	**Phoenix**	**Safford**	**El Paso**
Water class	**C4-S3**	**C3-S2**	**C2-S2**	**C3-S1**
TDS, mmho/cm	**3.9**	**1.3**	**0.7**	**1.2**
SAR	**8.4**	**6.3**	**7.2**	**3.8**
Bicarbonate, ppm	**300**	**165**	**170**	**200**
Acid rate, ppm	**230**	**110**	**100**	**150**
pH before treatment	**8.0**	**8.2**	**8.6**	**8.2**
pH after treatment	**7.9**	**7.9**	**7.8**	**8.0**
	*Infiltration rate cm/day**			
Sonoita sandy loam				
no acid	**50**	**33**	**27**	**51**
acid	**57**	**49**	**45**	**53**
Anthony sandy loam				
no acid	**35**	**24**	**18**	**36**
acid	**40**	**34**	**30**	**37**
Cave loam				
no acid	**22**	**18**	**17**	**24**
acid	**25**	**20**	**19**	**24**
Grabe clay loam				
no acid	**8.9**	**5.9**	**2.9**	**7.8**
acid	**10**	**6.8**	**5.4**	**8.0**

**To convert to inch/day, multiply by 0.4.*

Acid application at rates exceeding the equivalent amounts of bicarbonate decreases the pH of water drastically and causes corrosion problems, so the pH should be checked. More details on the chemistry involved in water treatment with acid are given in reference 2.

In order to demonstrate the effect of water-applied acid on infiltration rates, laboratory infiltration tests were conducted for nonsodic soils. Table 2 shows some of the results. The steady state infiltration is obtained after soils come to equilibrium with a given irrigation water. Acid application at rates slightly lower than the equivalent amounts of bicarbonate improved water infiltration in some of the soils tested when the SAR of irrigation water was greater than about 7, such as the first three waters of Table 2. Application of acid to irrigation waters having lower SAR than the above, such as the last water of Table 2, is of little or no value in increasing infiltration rates unless soils are sodium-affected.

If sodium is very high and calcium is low, the above acid rates may not be sufficient. In this case, acid can be applied to irrigation water after the water has passed through the concrete or metal parts. Such operations are usually more time consuming and tedious. If anhydrous or aqueous ammonia is applied to irrigation water, acid can be applied simultaneously up to the equivalent amounts of ammonia without corroding irrigation system (3 tons of 95% acid is equivalent to 1 ton of NH_3). Irrigation systems should be flushed after using this mixture. Acid applied to ammoniated irrigation water not only reduces volatile losses of ammonia, but also prevents calcium precipitation.

Field Infiltration Tests

For determining necessary acid rates and the improvement of water infiltration or penetration, some field tests are usually required. Various methods are currently used depending on field situations. These include: measurement of water penetration depth shortly after watering, infiltration rates during irrigation, or measuring run-off water. Indirectly, improved water penetration can be evaluated in terms of water stress symptoms of crops.

One of the popular methods currently used is the infiltration test which measures the depth of water infiltration with time. In our tests, single-ring infiltrometers made of steel pipe (one foot in diameter and one foot long) were used. They were carefully driven into the ground to a 10 cm (about 4 in.) depth. Three replicates with prewetting gave satisfactory results. Some results are shown in Table 3 in terms of depth of water infiltrated during the designated time periods.

At St. David, concentrated acid at rates of 5 and 10 tons/ha (2.25 and 4.5 US tons/acre) was sprinkled on a severely sodium-affected soil once, prior to 20 cm (8 in.) irrigation. The high rate of acid doubled the infiltration rate in this case. In a similar test at Three Points, the low acid rate gave satisfactory results, probably because soils were silty and the ESP was lower than the case of St. David. At Willcox, concentrated acid was applied similarly, but at lower rates because of the lower ESP. Infiltration rates again nearly doubled. At Bowie, acid was applied to irrigation water at a rate of 100 ppm (or about 17 gallons per acre-ft. of water) for both the first and second irrigations. At the time of the first irrigation the soil was extremely dry, where as it was moist before the second irrigation. Thus the absolute values are not directly comparable between the two irrigations. The Marana test was conducted by a former graduate student, E. Margolis, by applying rather high rates of acid during the first irrigation. These field data generally agree with the laboratory results, showing that acid is effective when soils and/or waters contain excess sodium.

An adequate discussion of crop response to improved water pentetration by acid is beyond the scope of this paper. In brief, sorghum growth and yields were improved at Willcox by soil treatment with 3 tons acid/ha (1.35 US tons/acre) and leaching (Fig. 1). Cotton growth at Bowie was improved by water treatments using 100 ppm acid or the total acid rate of 0.3 tons/ha (0.135 US tons/acre), divided into three irrigations. No significant difference in sudangrass yields was observed at Marana where sodium was not a cause of poor water penetration.

Suggestions for Field Applications

The first logical step of using acid is to identify the reason of poor water

Table 3. Effect of soil or water applied acid on infiltration in the fields after 24 hours.**

Locations		*Acid*	*Infiltra*	
Soils	*Water*	*Rate*	*1st Irrig.*	*2nd Irrig.*
		tons/ha	*cm*	
Soil Applied				
Merril Farm at St. David				
clay loam	**C2-S2**	0	8	7
ESP = 67	**SAR = 6.5**	5	12	10
TDS* = 1.7	**TDS = 0.8**	10	19	15
Buckelew Farm at Three Points				
silt loam	**C2-S4**	0	6	6
ESP = 38	**SAR = 30**	5	16	15
TDS = 3.0	**TDS = 0.3**	10	17	17
Collins Farm at Willcox				
clay loam	**C2-S2**	0	9	8
ESP = 25	**SAR = 5.7**	3	19	17
TDS = 8.4	**TDS = 0.5**			
Water Applied (ppm)				
Wardlaw Farm at Bowie				
silt loam	**C2-S4**	0	13	9
ESP = 11	**SAR = 30**	100	20	15
TDS = 1.2	**TDS = 0.6**			
*U of A Farm at Marana***				
clay loam	**C2-S1**			
ESP = 3.4	**SAR = 2.5**	0	6.9	4.4
TDS = 0.6	**TDS = 0.4**	425	6.7	5.0

**TDS (Total Dissolved Salts) in mmho/cm in saturation extract or in irrigation water.*
***Marana farm readings were made after 1.5 hours.*

penetration. Soil and water analyses are useful for this purpose. Acid may help if the exchangeable sodium percentage of soils is greater than about 10 and/or the sodium adsorption ratio of irrigation water greater than about 7 in fine-textured soils. This is, however, a rough guide and the acid effect will vary depending on soil types, total dissolved salt, and the method and rate of acid application.

The second step is to determine the method of acid application and estimate the approximate rates. When soils contain high sodium and lime, soil treatment is logical. (Soil treatments also have the advantage of releasing phosphorus and certain micronutrients locked in calcareous soils.) Acid rates for soil treatment vary widely, but as a rough guide, ranging from 1 to 3 US tons/acre for marginally sodium-affected crop land and 3 to 6 tons/acre for severely sodium-affected land. If irrigation water quality is good, one-time application will last for many years. Acid rates for water treatment vary depending on water quality, severity of the problem and the rate of ammonia used, but ordinarily range from 100 to 200 ppm or 0.5 to 1.5 US tons/acre per growing season. Acid rates that can be applied at one time through irrigation systems containing concrete ditches or metal pipes should be less than about 90% of the equivalent bicarbonate content if ammonia is not applied. Table 4 shows the maximum acid rates for surface irrigation systems.

The third step is testing to confirm the effect of acid on water penetration and determining necessary acid rates. Several methods described in the previous section can be used depending on field situations. At this stage it is necessary to consider if acid treatment is superior to other means of improving water penetration such as changing irrigation techniques and land slopes, using other chemical amendments, etc.

The fourth step is the field application which requires special care, since sulfuric acid is corrosive and hazardous. Professional advice and assistance are essential. For soil treatment, acid is applied by tractors or trucks equipped with sprinklers under gravity flow. After the surface application of acid, adequate water must be provided to leach salts produced by acid away from seedling or root zone. If soils are originally salty, large amounts of leaching water, about one foot, are needed. For water treatment, acid can be applied into irrigation waters. If ammonia is applied through irrigation water, it is better to apply acid up to allowable maximum levels than to apply acid during every irrigation.

The final step is the evaluation of acid effects which can be done in terms of crop yields and reduction in tail water or in irrigation frequency. In addition, acid effects can be evaluated in terms of improved utilization of nitrogen when ammonia and acid are applied to irrigation water and phosphorus and certain micronutrients following soil treatment.

Table 4. Maximum rates of concentrated acid (95%) used for irrigation water treatment with systems containing concrete ditches or metal pipes.

Bicarbonate (HCO_3^-)		*Acid Rates**			
ppm		*ppm.*	*ton/ha-m*	*lb./acre-ft.*	*gal.†/acre-ft.*
50		38	0.38	101	6.6
100		76	0.76	203	13.3
150		114	1.14	304	19.9
200		152	1.52	407	26.7
Ammonia (NH_3)					
ppm	*lb./acre-ft.*				
25	67	76	0.76	203	13.4
50	134	152	1.52	407	26.7
100	268	304	3.04	814	53.4

**This standard of acid rates for waters containing bicarbonate should not be used for sprinkler system.*

†One gallon of concentrated acid weighs 15.3 lb. or 6.9 kg, and a 55-gallon drums holds 840 lb. or 382 kg.

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