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Effects of soil amendments on crusting, seedling emergence and yield of onion, tomatoes and peppers

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EFFECTS OF SOIL AMENDMENTS ON CRUSTING, SEEDLING EMERGENCE AND YIELD OF ONION, TOMATOES AND PEPPERS

by

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As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Mohamed Mohamed Yacoub

entitled Effects of Soil Amendments on Crusting, Seedling Emergence and Yield of Onion, Tomatoes and Peppers

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

Jack L. Stroehlein
Dissertation Director — Date 15 April 1991

STATEMENT BY AUTHOR

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ABSTRACT

The effects of sulfur-containing amendments (H_2SO_4, $Al_2(SO_4)_3$ and gypsum) or crust formation, soil chemical properties, seedling emergence and yields of onions (Allium cepa), tomatoes (Lycopersicum esculentum) and chili peppers (Capsicum sp.) were studied on a Pima clay loam soil. Treatments were surface applied on a strip above the seeds.

The chemicals influenced the penetrometer index, soil-pH, electrical conductivity, DTPA-extractable soil Fe, Cu, Zn, Mu and seedling emergence in two greenhouse experiments. Gypsum and H_2SO_4 increased seedling emergence while $Al_2(SO_4)_3$ reduced the soil-pH and EC more than H_2SO_4 and gypsum. Based upon penetrometer readings, H_2SO_4 was the best anti-crusting agent tested followed by gypsum and $Al_2(SO_4)_3$. At the end of the study, all soil samples were very low in KCl extractable Al, showing that Al toxicity was not responsible for seedling damage. Gypsum decreased levels of Mn and Zn but did not affect Fe and Cu. $Al_2(SO_4)_3$ increased Fe and Zn, decreased Cu but did not affect Mn. H_2SO_4 did not affect extractable Mn, Cu, Zn and Fe levels.

In a field study using two water qualities at Safford, gypsum produced the most tomato seedlings whereas $Al_2(SO_4)_3$ and H_2SO_4 produced the least. Onion stand counts were not affected by the chemicals with either water. Gypsum, H_2SO_4 and $Al_2(SO_4)_3$ polymer produced the highest pepper stand counts with the saltier water but there were no differences with lower salt water. Tomatoes produced the

highest yield with gypsum and lowest with H_2SO_4 and $Al_2(SO_4)_3$ with saltier water. With lower salt water, gypsum produced highest yield, followed by the H_2SO_4. Both $Al_2(SO_4)_3$ treatments produced low yields. Onions showed no treatment response under lower salt water, while with saltier water, gypsum and H_2SO_4 produced the highest yields. Pepper yields were not affected by amendments with the lower salt water. $Al_2(SO_4)_3$ polymer, H_2SO_4 and gypsum increased yields with the saltier water.

Varieties of peppers and tomatoes produced different yields in response to water quality in a supplementary field study.

INTRODUCTION

Obtaining a satisfactory stand is one of the most consistent and perplexing problems faced by Arizona farmers. While some plant species can compensate over a range of stands, other species require precise stands for maximum yield and quality. Considerable effort is expended in order to use the proper seeding rate and spacing and desirable soil conditions for obtaining a good stand.

Seed emergence is a process resulting from inhibition of water, germination and emergence from the soil. Emergence can be restricted by a number of factors including high salinity which reduces available water to the seedling. A lack of moisture causes drying and excess moisture restricts available oxygen in the soil and a seedling may face one or both of these environmental factors before emergence. Other factors may be wind damage by blowing sand and diseases. Rainfall after planting or excess irrigation water can result in soil crusting, the formation of a hard dry soil layer above the seed. This study involves using various chemical amendments for crust control and improving seedling emergence.

Sulfur-containing chemicals for correcting soil salinity have been used for more than a century. Documents show that sulfuric acid and gypsum have been used as soil amendments for more than 90 years. There was no statistical analysis used, significance of their effectiveness in application was proven when statistics was introduced. Both chemicals were effective in reclaiming high sodium soils and improving the physical and chemical conditions of sodic soils.

A number of commercial anti-crusting agents have been shown to be effective, as well as some of the commonly used amendments and fertilizers, such as gypsum, sulfur, sulfuric and phosphoric acids. These materials may act to flocculate the soil and remove exchangeable sodium as in the case of gypsum and acids. Acids can also result in a vesicular structure due to the formation of carbon dioxide bubbles which form from the reaction of acid with lime in the soil. In this study, a commercial aluminum sulfate material (Boligrow) and its polymers were compared with gypsum and sulfuric acid as anti-crusting materials.

Sulfur-containing chemicals, such as sulfuric acid, gypsum and aluminum sulfate have been used for the correction of salt problems in sodium affected non-calcareous soils. Success with the materials was varied with the varieties, kind of salts and soils, as well as the methods of use and time.

In Arizona, sulfuric acid can be obtained from copper smelters. University of Arizona has conducted research on soil reclamation using sulfuric acid from the copper industry since 1922.

It seems that sulfuric acid and gypsum are well recognized for improving the physical condition of soils and overcoming the sodium problems.

The purpose of this research is to compare the effectiveness of sulfuric acid, gypsum, aluminum sulfate and its polymer on sodic soils using two water qualities in a field study; and the yield of three crops of vegetables (onion 'cv. Inca', tomato 'Castle Red,' and a commercial variety of chili peppers). The purpose of the greenhouse study is to compare the effect of sulfuric acid, gypsum, and aluminum sulfate on Safford salt-affected soil in reducing crust formation, pH and EC.

A supplementary field study involved the selection of varieties of tomatoes and peppers which are capable of producing good yields with moderately saline soils of the Safford Agricultural Center.

LITERATURE REVIEW

Crusting

Crust is a structure which develops in the top of soils and is characterized by few large pores, high bulk density, platiness, stratification and orientation of materials of different sizes (Kemper and Miller, 1974). In the same citation, Kemper and Miller reported that the characteristics of soil crusts and crusting as: 1) low organic matter with high silt and low aggregate stability; 2) high sodium (Na) levels; and 3) high run-off and erosion potential. Therefore, according to the crust characteristics, seedling emergence will be reduced or prevented.

McIntyre (1958) reported that the soil crust consists of an upper skin seal due to the compaction by rain-drop impact and a decreased porosity region attributed to the accumulation of silt and plate shaped particles. Rasmussen et al. (1972) reported that formation of a crust is a result of falling water drops which effectively destroys the original structure and causes crusting on the surface.

In a description by Kemper and Miller (1974), the crust is a hard and compact layer of low saturated hydraulic conductivity and limited infiltration; all those factors result in water run-off and erosion, and as the soil dries, the crust often becomes hard enough to prevent emergence of the seedlings.

Agassi et al. (1981) reported that there are two mechanisms of crust formation: 1) a physical dispersion of soil aggregates caused by the impact action of rain drops, and 2) a chemical dispersion which depends upon the soil exchangeable Na percent (ESP) and electrolyte concentration of the applied water.

Crusting and Sodicity

Kelley and Thomas (1928) showed that application of gypsum, sulfur, iron sulfate, or aluminum sulfate on black alkali soil (sodic) greatly improved the crop-producing power and the first foot of the soil was freed from soluble carbonate as a result of application of 10 tons/ha or more of gypsum, sulfur, iron sulfate or aluminum sulfate and the second foot was materially improved.

Pearson (1960) reported that exchangeable sodium causes an aeration problem, affects water movement, retards root growth and changes the soil physical condition or structure. Sodic soil restricts elongation and development of young seedlings. The hard crust forms on the soil surface of a sodic soil as it dries out, often hinders the emergence of young seedlings.

Kemper and Miller (1974) reported that crusting is found with silty soils and the problem is increased by exchangeable sodium. The problem is increased by low salt or high sodium waters, rainfall, and saturated soil due to irrigation, all of which reduced or destroyed soil aggregation stability.

Brady (1984) defined sodic soils or black alkali soils as having an electrical conductivity below 4 dS/m, a pH higher than 8.5, and the ESP higher than 15% of the total exchangeable capacity.

Crusting Control

Crust affects seedling emergence and reduces the number of seeds germinated. The use of a number of chemicals for crust prevention and control of crusting with different crops has been studied by a number of researchers.

Powers (1946) and Miyamoto et al. (1975a) reported that sulfuric acid showed an effectiveness in controlling alkali soil crusts and improving soil conditions. Olson (1950) concluded that an increase in yield and a decrease in chlorosis with chlorosis-producing soils was a result of sulfuric acid treatment. Overstreet et al. (1951) found that sulfuric acid treatment resulted in a higher leaching rate in a silt loam soil than with gypsum treatment.

Johnson and Law (1967) found that sulfuric acid applied to the soil surface over sugar beet seeds reduced crusting and improved seedling emergence for spring plantings while Dennis and Wudiri (1976) reported that germination of seeds was reduced from surface applied acid in fall-planted sugar beets in Arizona; the poor results were attributed to high salinity resulting from the acid application and high temperature at planting time.

Kemper and Noonan (1970) reported that gypsum was used to increase infiltration on sodium-affected soils and to help flocculate the soil. Kemper and Noonan (1970) and Kemper and Miller (1974) reported that gypsum applications increased emergence of seedlings and decreased surface crusting.

Rasmussen et al. (1972) showed that some Na^+ problems in the soil surface can be improved by disking and bringing up gypsum from deeper soil layers to the surface.

Bicarbonate removal from water with sulfuric acid can improve nutrient uptake (Ryan and Stroehlein, 1973) and can be beneficial in reducing soil crusting, where precipitated calcium carbonate acts as a cementing material (Miyamoto et al., 1975b; Ryan et al., 1973).

Kemper and Miller (1974) found that phosphoric acid sprayed over the seeded row showed the same result as gypsum in increasing seedling emergence and decreasing surface crusting.

Loveday (1975) reported that in controlling soil crusting by using acid, seedling emergence and establishment may be improved and an advantage such as reduced tillage and improved fertility may occur. Kadry (1978) reported that sulfuric acid, gypsum, and iron sulfate have been successfully used to neutralize the pH of alkaline soils and replace sodium with calcium.

Sodium is one of the important factors in crusting formation. Alawi (1977) reported that gypsum can be used in reclamation of sodic and saline-sodic soils when they are not calcareous, while with enough calcium carbonate in the soil, sulfuric acid will be more beneficial than gypsum. The action of gypsum and sulfuric acid can be shown as follows:

A. Gypsum

$$2Na[\; + CaSO_4 \rightarrow Ca[\; + Na_2SO_4$$

where Na[: is the exchangeable Na and Ca[: is the exchangeable calcium. The resulting $NaSO_4$ is a very soluble salt which can be leached easily from the soil.

B. Sulfuric acid

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + CO_2 + H_2O$$

$$CaSO_4 + 2\ Na[: \rightarrow Ca[: + Na_2SO_4$$

In a report by Stroehlein and Pennington (1986), leaching and amendment needs are based mainly upon soil salinity, ESP, solubility of the carbonates, texture and mineralogy. Thus, reclamation is based on applying the proper kind and amount of amendments and leaching to flush the soluble salts including the Na below the root zone.

Generally speaking, the effectiveness of sulfuric acid, gypsum, and aluminum sulfate is related to crusting prevention which improves the potential for seedling emergence and plant growth. Miyamoto and Stroehlein (1986) showed that sulfuric acid provides faster leaching water movement than does an equivalent rate of gypsum in numerous sodium-affected soils and sulfuric acid showed a greater removal of Na than gypsum. Prather et al. (1978) reported that sulfur amendments can increase the infiltration rates for low-salt water, help maintain and improve the sodium absorption ratio (SAR) and possibly help in leaching of excess boron.

The importance of sulfuric acid has been proven by scientists and researchers as it increases the infiltration rate, reduces crusting which has the most adverse affect on seedling emergence or preventing germination. Other sulfur containing materials such as gypsum, aluminum sulfate, and iron sulfate showed similar affects. Stroehlein (1978) reported that sulfuric acid amendments are promoted for their value in improving soil fertility of alkaline soils. Miyamoto and Stroehlein (1986) reported that sulfuric acid is known to improve infiltration, and so are other amendments such as calcium chloride and gypsum.

Some scientists such as Gardener (1945) studied leaching and clay dispersion and reported that in Na soils, clay tends to disperse to a considerable extent and become mobile under field conditions, especially if the salts are leached from the soil and low salt water is used for irrigation.

Using chemicals in soil reclamation was successful in reducing the Na^+ affect on soils and crops in research reported by McCormick and Naphan (1952). They showed that gypsum, sulfur, sulfuric acid and aluminum sulfate were successfully used in replacing exchangeable sodium-clay with calcium clay. Tisdale (1970) reported that aluminum sulfate, ammonium thiosulfate solution, calcium polysufide solution, ferrous sulfate, gypsum, sulfur, sulfuric acid and sulfur dioxide are sulfur-containing chemicals that can be used in treating and reclaiming soils affected by sodium salts.

Sulfuric Acid As An Amendment

McGeorge (1945) found that the addition of small amounts of sulfuric acid to irrigation water reduced the soil pH and increased phosphorous absorption by plants. Christensen and Lyerly (1954) and Mohamed (1972) reported that reduction in soil pH and ESP and increase in soil permeability were a result of using acidifying amendments. Overstreet et al. (1955) showed that sulfuric acid was more effective than gypsum in reclaiming sodic soils.

Schoonover et al. (1957) reported that an application of sulfuric acid removed exchangeable sodium and improved permeability as well as resulted in an increase in crop production.

Christensen and Lyerly (1954) and Ryan and Stroehlein (1973) reported that availability of several micronutrients increased as a result of using sulfuric acid on salt-affected soil.

Fuller and Ray (1963) reported that gypsum was produced from insoluble calcium carbonate as a result of sulfuric acid reaction with the soil. Fannin's Farm Facts (1954) and Miyamoto and Stroehlein (1986) reported that sulfuric acid reacts with calcium carbonate to form calcium bicarbonate and calcium sulfate, both of which react to displace the undesirable sodium ion; during the same process, calcium left in the soil from the sulfuric acid treatment causes a flocculation of the fine particles resulting in more porous soil which aids water penetration.

Mathers (1970) reported that treating calcareous soils with sulfuric acid increased sorghum hybrid grain yields and reduced the pH in field and greenhouse studies. Stroehlein et al. (1978) confirmed that the soil pH was reduced as a result of sulfuric acid application.

Petrosian (1974) showed that sulfuric acid application at low concentrations resulted in replacing exchangeable Na, neutralizing alkaline medium, coagulating hydrophilic colloids and a sharp decrease of soil dispersity, therefore, enhancing water infiltration and salt removal during operation leaching. Formation of gypsum, sodium, and magnesium sulfate is a result of the application of sulfuric acid which reacted with decomposed calcium and magnesium carbonates of sodic soils.

Miyamoto et al. (1973; 1974) reported that using sulfuric acid creates a layer of acidic nature on the soil surface and the stability of aggregation of the layers was reduced in most calcareous soils.

Gupta and Bajpai (1977) reported that the chemical and physical conditions of saline-sodic soil were improved as a result of treatment with sulfuric acid followed by leaching.

According to Stroehlein (1978), surface applied sulfuric acid is fast acting, safe after soil application, may be leached immediately and crops planted, and usually more effective than other sulfur compounds when used on calcareous soils. Before the crops could be grown, sulfuric acid action is required to release the salts and then leaching is needed to flush them below the root zone. Prather et al. (1978) and Stroehlein et al. (1978) reported that application of sulfuric acid directly to the soil or in the irrigation water is effective for removing salts from calcareous soils.

O'Conner and Lee (1978) showed that sulfuric acid was effective in preventing exchangeable sodium build-up. Sulfuric acid decreased the ESP (Miyamoto et al., 1975a) and lowered the soil pH (Ryan et al., 1974; Stroehlein et al., 1978; Yacoub, 1984), as well as increased the permeability of soil which helped in removing the salts by leaching (Prather et al., 1978). Velasco (1981) reported that addition of concentrated sulfuric acid lowered the soil pH and ESP in the first 20 cm and was not effective below 20 to 40 cm in sodic and calcareous soils.

Soils of low calcium carbonate content allows sulfuric acid to reduce the soil pH, acidifying the soil (Ryan and Stroehlein, 1973; Tavassoli, 1980).

Stroehlein and Pennington (1986) reported that soil reclamation can be done by adding sulfur-containing materials which is two ways of adding calcium: direct addition of calcium sulfate and reaction of acid forming materials on calcium carbonate in the soils.

In a conclusion by Miyamoto and Stroehlein (1986), that in numerous sodium affected calcareous soils, sulfuric acid application resulted in faster leaching water movement than does an equivalent rate of gypsum; also sulfuric acid reacted with calcium carbonate to form gypsum which has been used for reclaiming calcareous sodic soils. They also reported that gypsum and sulfuric acid removed approximately equal amounts of sodium, whereas in many sodium affected soils, acid showed a greater removal of sodium than gypsum.

Overstreet et al. (1951) and Stroehlein and Pennington (1986) reported that sulfuric acid is generally superior to other amendments for removing Na from calcareous soils because it reacts immediately in the soil to form colloidal gypsum and increases the soluble salt content which flocculates the soil particles.

Gypsum As An Amendment

Gypsum is considered to be a safe and effective chemical for treating sodic soils. Kelley and Arany (1928) reported that gypsum effectiveness depends upon its solubility in reclaiming sodic soils and the presence of sodium chloride which increased the solubility of gypsum in the soil.

Kelley and Thomas (1928) showed that application of gypsum at 10 tons per acre or more, uniformly, produced successful results on a black-alkali soil as the first foot of soil was freed from soluble carbonates. Botkin (1933) and Fireman et al. (1950) reported that gypsum was the most effective amendment in replacing sodium of sodic soils and a most economical chemical.

Botkin (1933), McGeorge (1945), Bower et al. (1951), and McCormick and Naphan (1952) reported that gypsum is used to reclaim black-alkali soils and to prevent its development, maintain good structure, soften tight soils, improve water penetration rate and soften the hard-pan.

McGeorge (1945) reported that gypsum is an excellent, effective and useful amendment for reclaiming both black and white alkali soils and improving structure of irrigated soils. Gardener (1945) showed that gypsum is an effective chemical that increased the soil permeability, as well as capillary movement and made the soil friable.

McCormick and Naphan (1952) reported that gypsum was spread according to the degree of the salt severity of the soil and disked to prevent blowing and improve soil structure.

Bower et al. (1951) and Schoonover et al. (1957) reported that gypsum application removed exchangeable sodium and improved soil aggregation percent and permeability as well as resulted in high crop production. Schoonover (1953) and Fuller and Ray (1963) and Stroehlein and Pennington (1986) reported that gypsum effectiveness is governed by its solubility, fineness and purity; thus it should be finely ground in order that the solubility will be relatively high. Thus, gypsum should be mixed with the soils in order to increase its contact and solubility as well as its effectiveness. Gypsum has been shown to be effective in reducing the sodium content of soils in the Safford area, but rates required are generally excessive (McGeorge et al., 1952; Dutt et al., 1972).

Mohamed (1972) reported that gypsum supplies calcium directly to replace the exchangeable sodium and sulfuric acid dissolved calcium and magnesium carbonates and bicarbonates which will replace the exchangeable sodium that can be removed by leaching. He concluded that addition of sulfur-containing compounds to low salt irrigation waters improved water movement through the soil. Gypsum and sulfur dioxide showed an increased permeability when both high and low salt waters were used. Gypsum was more economical than sulfur dioxide.

Soils treated with calcium (gypsum) showed correction of the undesirable physical properties caused by ESP of 5 to 6 or more (Loveday, 1975) and reduced the ESP of sodic soils (Stroehlein, 1978).

Gupta and Bajpai (1977) reported that gypsum and calcium chloride treatment followed by leaching improved the chemical and physical conditions of saline-alkali soils.

Gypsum lowered the soil pH and ESP (ESP 15 to 25 or more) and the reduction was more in the first 20 cm zone than in 20 to 40 cm zone in sodic and calcareous soils (Velasco, 1981). Cates et al. (1982) showed that gypsum reduced soil EC and pH values as well as increased barley dry matter production. This increase was due to the improvement of soil nutrient status by both gypsum and sulfuric acid application.

Aluminum Sulfate As An Amendment

Aluminum sulfate ($Al_2(SO_4)_3 \cdot 18H_2O$) is one of the sulfur containing soil amendment chemicals.

Johnston and Powers (1924) reported that aluminum sulfate improved the physical condition and increased the water movement of the soil. Kelley and Arany (1928) documented that alum (aluminum sulfate), iron sulfate and sulfur were effective in reclaiming sodic soil and improved the physical conditions and crop growth.

Botkin (1933) reported that iron sulfate and aluminum sulfate reduced soil alkalinity and facilitated water percolation and improved permeability in alkali (sodic) impermeable soils.

Powers (1946) reported that aluminum sulfate has been used in amounts varying from 500 kg to 11 tons per hectare which depends upon the type of soils and the severity of the salt problem, and as a result of these treatments, the soil physical conditions and permeability were improved.

Bower (1959) reported that aluminum sulfate and iron sulfate are solid, granular materials, which usually have a high degree of purity and are soluble in water; when applied to soils, they dissolve in soil water and decompose to form sulfuric acid which in turn supplies soluble calcium through its reaction with lime such as:

$$Al_2(SO_4)_3 + 6H_2O \rightarrow 2\ Al(OH)_3 + 3H_2SO_4$$

$$Fe\ SO_4 + 2H_2O \rightarrow Fe(OH)_2 + H_2SO_4$$

Sulfur, sulfuric acid, lime-sulfur, iron sulfate and aluminum sulfate application resulted in reducing the ESP and soluble salts of sodic soils. He also reported that aluminum sulfate, iron sulfate, gypsum, lime-sulfur, and sulfur applied by broadcasting and incorporating into the soil by plowing or disking reduced the severity of sodium affect in sodic soils. Sulfuric acid, iron sulfate and aluminum sulfate are generally expensive which was the only objection to using them as amendments for salt affected soils.

Stroehlein and Pennington (1986) reported that as a result of hydrolyzation of aluminum sulfate and iron sulfate, the produced sulfuric acid reacts with lime and provides soluble calcium as the direct application of gypsum. Sulfuric acid improved nutrient availability for the plants.

MATERIALS AND METHODS

Field and greenhouse studies were conducted using a soil from the Safford Agricultural Research Center. According to McGeorge et al. (1952), Safford Farm soils irrigated with water from the farm well, which is high in salts, resulted in soils that developed a high Na percentage and deterioration in soil structure.

The Gila Valley surrounding Safford, Arizona, is typical of many irrigated areas because it is known for its heavy soils that are moderately affected by excess soluble salts and sodium, a direct effect of using well water high in salt and sodium content. This soil is subjected to changes in water quality depending on the availability of river water supply, which leads to such problems as slow infiltration, water logging, and crusting (Alawi et al., 1980). The soil taken from field C is classified as Pima clay loam variant, fine silty, mixed thermic family of Typic Torrifluvents (Post et al., 1977). The soil generally contains 2.1% $CaCO_3$, has a pH of 7.9, and EC_e of 5.6 dS/m. With such alkaline conditions, the solubility and availability of aluminum and iron are very low. Iron deficiency is common at the center when crops such as grain sorghum (Sorghum vulgare) are grown.

The soil has a clay loam texture and a high content of montmorillonite clay. Such soils are susceptible to shrinking, swelling, cracking and crusting. Stand establishment with this soil is often difficult. Switching of low salt containing Gila River water with saltier well water contributes to problems with soil physical condition.

An experiment was conducted to study the effect of sulfur-containing chemicals on soil crusting in which sulfuric acid, gypsum, and aluminum sulfate were compared against a control (zero treatment) in a University of Arizona greenhouse.

Another experiment was laid out in Field C of the Safford Agricultural Research Center. The experiment was conducted to study the effect of water quality with respect to crusting of sodic soil. These effects were compared with the effects of the amendments on plant yields of tomatoes (Lycopersieum esculentum), chili peppers (Caspium sp.) and onions (Allium sepa).

A supplementary field study compared the yields of several cultivars of tomatoes and peppers when grown with the two water qualities at Safford.

The Greenhouse Studies

This study was conducted in planter boxes with dividers to test the effect of sulfur-containing materials on crusting of Safford soil in which sulfuric acid, gypsum, and aluminum sulfate (Boligrow) were compared against control (zero treatment) in a greenhouse on the University of Arizona campus. Boligrow is a commercial product of aluminum sulfate used for soil treatment and reclamation.

The soil was collected from Field C Pima variant Site 2 at Safford of mixed top soil. The soil was ground, sieved (2 mm mesh) and arranged in boxes as in furrow system. The soil depth was 6 cm in average, and approximately 9 kg of soil was used for each division.

A randomized complete design with three treatments and a control with 15 replications with a total of 60 strips (rows) were used for the experiment. The rows were in boxes of 60 x 60 cm. Each box was used for three rows, 20 cm apart and 60 cm in length (see Fig. 1).

The treatment additions were made according to the area of each division which was 20 x 60 cm or 1200 cm^2 (0.12 m^2). The chemical treatments were applied on a strip above each seed row. Twenty seeds of 'Rosa' tomato (Lycopersicum esculentum) were sown on 4 January 1987 with a spacing of 2.8 cm apart in the row. Boxes were irrigated with tap water (EC_w = 0.4) until saturated.

The chemical treatments were applied at a rate of 500 kg/ha sulfur as follows: i) sulfuric acid applied was 187.5 ml of 1N on each row, ii) aluminum sulfate (Boligrow) 41.65 g on each row and (iii) gypsum 32.25 g per each row.

Ten days after planting, emergence count was recorded daily for 35 days until 22 February 1987.

A second trial of same rates, amendments, seeds, and soil, was conducted on 15 March 1987 and seed emergence was recorded. In the second trial, penetrometer readings were recorded. A penetrometer model CL-700 made by Soiltest, Inc. was used in measuring the crust formation strength. The recording of seed emergence was taken for 28 days beginning 10 days after sowing.

Soil samples (2.5 cm depth) of the three treatments and the control were taken randomly at the end of the experiment. Four samples of each treatment were

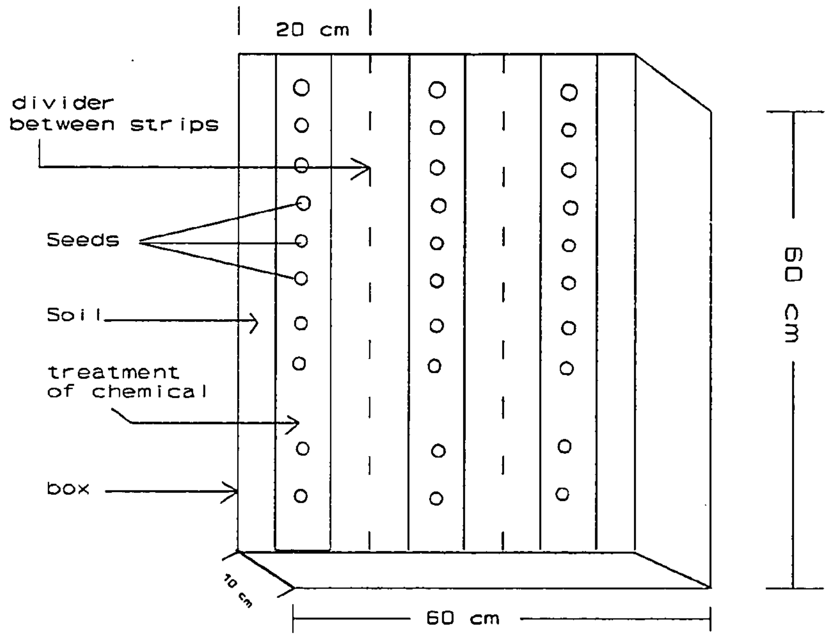

Figure 1. Box (60 x 60 cm) showing three strips and the treatment application above the seed rows.

taken to the lab of the University of Arizona. The pH and EC were measured on the samples following the USDA Salinity Handbook (1954). The pH and EC were measured on the basis of saturation paste (EC_e) and on one part soil and one part water ($EC_{1:1}$) basis. Also, aluminum extracted with buffered 1 m KCl solution and using atomic absorption and inductively coupled Plasma Optical Emission Spectrometry method was determined. The DTPA (Diethylenetriaminepentaacetic acid) method was used in extracting iron, manganese, zinc and copper and each element was determined by atomic absorption (Page et al., 1982).

Statistical analysis of randomized complete design was used for seed emergence, pH, EC, and for Fe, Mn, Cu, Zn and Al data.

The Field Study

Two water qualities were used for irrigation. They were Safford city water (less saline) and well water (saline) whose salinities were 1.15 and 2.21 dS/m, respectively. Chemical analysis of the water qualities are shown in Table 1. Furrow irrigation was the method of watering.

The experiment was a randomized complete block with six treatments including the control and eight replications with a total of 48 plots for each crop. Each plot was 3.28 x 1 m. The layout is shown in Figure 2.

Three vegetable crops of tomato 'Castle Red', onion 'Inca' and chili pepper 'New Mexico 6-4' were selected for the study. Seeding with Planet Jr. seeder at

Table 1. Chemical analysis of city and well waters that were used to irrigate tomato, onion and chili pepper plots, Safford Agricultural Center, 1986.

Water	EC	Soluble Salts	pH	Ca	Mg	Na	Cl	SO_4	HCO_3	NO_3	SAR
	dS/m	ppm		-----	-----	-----	-----	mg/l	-----	-----	
City	1.15	777	7.80	80	15	147	170	105	185	<2	3.95
Well	2.21	1591	7.35	78	14	415	334	200	483	6.5	11.39

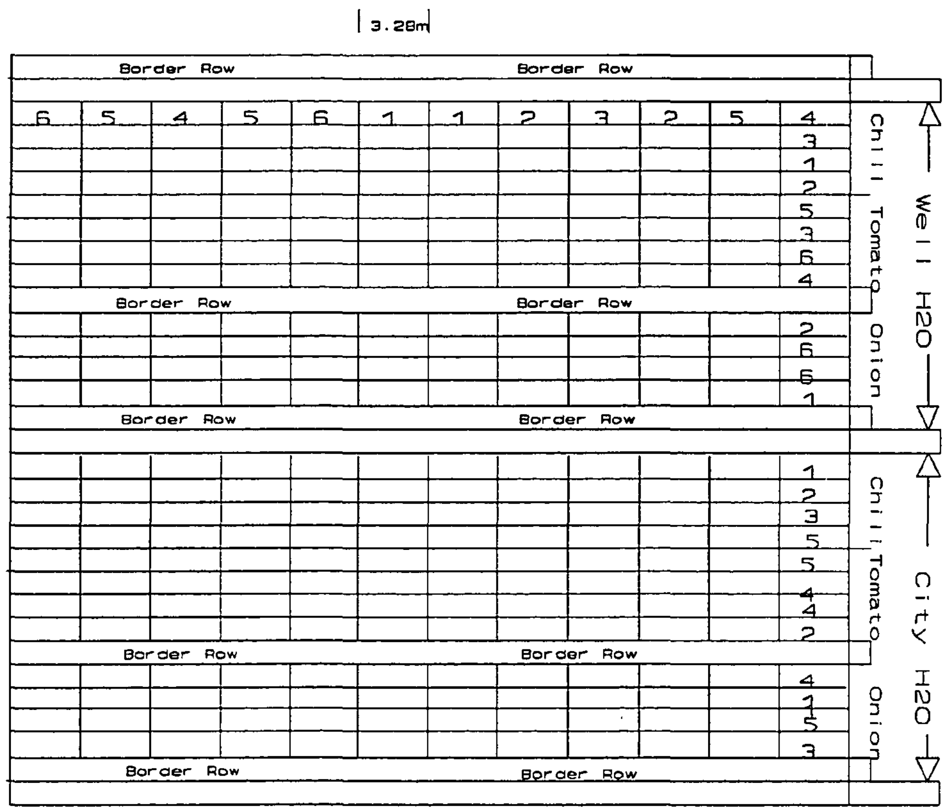

Figure 2. The lay-out of tomatos, onions and chili peppers in the field with the two water sources for irrigation.

approximately tomato at 157 seeds, onion at 124 seeds, and chili peppers at 77 seeds per plot.

The treatments of the sulfur-containing chemicals were sulfuric acid, gypsum, Boligrow (aluminum sulfate) and Boligrow polymer. The treatments were in different rates as shown in Table 2a for chili peppers and Table 2b for onions and tomatoes.

The addition of the chemical was on the basis of equal amounts of sulfur in each treatment which was approximately 150 or 300 kg/ha.

The field preparation was on 19 March 1986, chili peppers, onions and tomatoes were seeded using Planet Jr. Seeder on 20 March 1986, and the treatments were applied immediately after sowing. On 21 March, 100 kg/ha of urea and 200 kg/ha of 16-20-0 were added to both irrigation waters. On 20 April 1986, 200 kg/ha of triple super-phosphate were added and on 15 May 1986, 100 kg/ha urea and 200 kg/ha of 16-20-0 were added in the irrigation waters.

Two weeks after planting, the first stand counts were taken and 4 weeks later, the second stand counts were recorded. Also, thinning of the three vegetables were thinned to commercial stands after the second stand counts were made.

The yields of the three vegetable crops were recorded as an indication of the effects of the sulfur-containing chemical in reducing crusting hazards in the soil. The tomatoes were harvested twice on 24 July 1986 and on 10 August 1986. On 17 August 1986, chili peppers were harvested, and onions were harvested 3 days later. The yields were recorded for statistical calculations.

Table 2a. The treatment rates that were added to the chili pepper plots.

Treatment	Rate (kg/ha)
Control	No treatment (check)
Boligrow	1000
Boligrow with polymer	1000
Polymer	500
Sulfuric acid	500
Gypsum	830

Table 2b. The treatment rates that were added to the onion and tomato plots.

Treatment	Rate (kg/ha)
Control	No treatment (check)
Boligrow I	1000
Boligrow II	2000
Sulfuric acid I	500
Sulfuric acid II	1000
Gypsum	830

A statistical analysis for stand counts and yield was conducted to test the effect of the chemicals and water qualities on the soil and vegetable production. The statistical design was a randomized complete block (Little, 1960).

A supplementary study on tomato and pepper varieties was conducted in January 1986. Seeds of tomatoes: cvs. Columbia, Pearson, Beefsteak, Salad Master, and Rutgers; and peppers: cvs. Anaheim, Jalapino, California Wonder, New Mexico 6-4, and Libyan Pepper were planted in a greenhouse on the University of Arizona campus. The seeds were sown in quartz sand trays. A solution of ammonium nitrate containing 5 ppm N was added on 31 January 1986 and on 6 February 1986. An addition of 25 ppm P and 11 ppm N of $NH_4H_2PO_4$ was applied on 12 and 24 February 1986. The plants were transferred to styrofoam cups which contained sand and taken to the Safford Agricultural Research Center.

On 22 March 1986, the seedlings were transferred into the field at the Safford Agricultural Center. The spacing between plants was 50 cm and the row spacing was 100 cm. The two water qualities of EC 2.21 and 1.15 dS/m (Table 1) were used for irrigation. Fertilizer was applied similarly to the above field study of vegetable crops. No amendments were used in this study. Different colored tapes were used to differentiate the varieties.

The yields were recorded as a screening for the varieties for tolerance to salinity by comparing the two water qualities and their production. Statistical analysis was not conducted on yields of the tomato and pepper varieties.

RESULTS AND DISCUSSION

The Greenhouse Study

In the first experiment sulfuric acid and gypsum were significantly different from the control which was significantly higher than aluminum sulfate in seeds emerged.

The H_2SO_4 and $CaSO_4.2H_2O$ showed a significant effect in increasing the emergence number of the tomato seeds (Table 3).

Aluminum sulfate showed the least number of seed emerged, which was significantly less than the control. Also, some seedlings died after germination in the aluminum sulfate treatment which could be due to the chemical being on the top of the soil.

The sulfuric acid and gypsum doubled the number of the seeds emerged of the control, therefore, it may be worthwhile to use either chemical to reduce the crust effect and increase emergence numbers.

In the second experiment, the results were parallel to the first experiment in the order of the significance as the sulfuric acid and gypsum resulted in the highest emergence followed by the control and aluminum sulfate, respectively (Table 3).

In the second experiment, the length of the experiment was 4 weeks and the emergence number was higher with sulfuric acid and gypsum as well as aluminum sulfate which was doubled that of the first experiment (Table 3). The higher numbers of emergence with aluminum sulfate in the second experiment may be

Table 3. The average of seedlings emerged with the chemical treatments in the greenhouse.

	1st Experiment Average Number of Seedlings per Treatment	2nd Experiment Average Number of Seedlings per Treatment
Control	6.6 b*	6.2 b*
H_2SO_4	11.9 c	15.9 c
$Al_2(SO_4)_3$	1.1 a	2.6 a
$CaSO_4$	12.7 c	13.8 c

*Means followed by the same letter are not significantly different at the 0.05 level according to LSD test.

related to the irrigation water which was twice a day to give enough water for leaching and dissolving the aluminum sulfate.

Penetrometer readings were recorded in the second experiment and resulted in significant differences among all agents. Higher penetrometer readings indicate crusts formation and more resistance for seed emergence. Sulfuric acid showed the lowest readings which were significantly different from gypsum, aluminum sulfate and the control in that order. The control showed the highest readings which are the translation of crusting strength formation followed by aluminum sulfate which reduced the crust strength in terms of the penetrometer readings (Table 4).

The penetrometer readings indicated that sulfuric acid was the best anti-crusting agent to be used on crust-affected soil (Table 4). Gypsum and aluminum

Table 4. Treatment effect on soil crusting and seedlings emerged in the greenhouse.

Chemical Treatments	Penetrometer Readings (x) kg/cm^2
Control	.87d*
H_2SO_4	.55a
$Al_2(SO_4)_3$	.79c
$CaSO_4$	.75b

*Means followed by the same letters are not significantly different at the 0.05 level according to LSD test. Means of 15 replications.

sulfate, respectively, followed the sulfuric acid in their effect on the crust formation as anti-crusting chemicals. Therefore, sulfuric acid is to be considered the best anti-crusting agent followed by gypsum and aluminum sulfate vs, control, respectively, to be used on crust-affected soils to increase the seed emergence and reduce the force of the crust that retards seed emergence.

Sulfuric acid and gypsum reduced the crusting and increased the seed emergence (Table 4). The control has a higher seedlings number than aluminum sulfate even though the aluminum sulfate reduced the crust formation as shown by a significant difference against the control in the penetrometer index. The reason for the low emergence numbers may be related to the application of aluminum sulfate on the top of the soil which may cause toxicity to the sensitive germination seedlings.

In both greenhouse experiments, the pH (Table 5) was reduced significantly by the aluminum sulfate, sulfuric acid and gypsum compared to the control. The aluminum sulfate was the most effective in reducing the pH, and reduced the seedling number which may be due to its toxicity on the top of the soil surface.

Sulfuric acid and gypsum reduced the pH significantly against the control (Table 5), and reduced the crusting strength which resulted in increasing emergence rates of tomato seedlings.

Soil Analysis

Aluminum: The aluminum analysis showed very low amounts which was less than 1 mg/kg soil in all the samples of the greenhouse studies. Since these amounts were insignificant to seedling growth and significant differences were not found, data are not shown.

Manganese: The gypsum showed the least amount of Mn of 44.8 and 22.6 mg/kg soil in the first and second experiment, respectively (Table 6). In the first experiment, Mn was not significantly different in the aluminum sulfate and sulfuric acid against the control but all three were significantly higher in Mn than the gypsum treatment. In the second experiment, aluminum sulfate was the highest and was significantly different than sulfuric acid and the control which were not significantly different. Gypsum was the least significant against the other treatments and control (Table 6).

Table 5. The effect of the treatment on the soil pH and seedlings emerged.

	1st Experiment		2nd Experiment	
Treatment	pH	# of Seeds Germinated	pH	# of Seeds Germinated
Control	8.02 d*	6.7 b*	8.19 d	6.2 b*
H_2SO_4	7.41 b	11.9 c	7.52 b	15.9 c
$Al_2(SO_4)_3$	6.33 a	1.1 a	6.23 a	2.6 a
$CaSO_4$	7.85 c	12.7 c	7.98 c	13.8 c

* Means followed by same letter are not significantly different at the 0.05 level according to LSD test. Means of 15 replications,

Table 6. Manganese content of Safford soil resulting from amendment applications for the first and second greenhouse experiment.

	1st Experiment	2nd Experiment
Treatment	Mn mg/kg soil	Mn mg/kg soil
Control	63.4 b	35.8 b
H_2SO_4	69.3 b	38.5 b
$Al_2(SO_4)_3$	72.3 b	51.5 c
$CaSO_4$	44.8 a	22.6 a

* Means followed by same letter are not significantly different at the 0.05 level according to LSD test. Means of 4 replications.

Both experiments showed parallel correlation between Mn and pH values of the chemicals and control (Table 6). All samples showed that the amount of Mn was lower in the second experiment than in the first experiment which may be due to the high amount of water applied in the second experiment as irrigation was twice a day due to high temperature. As a result of more water used, more leaching apparently occurred which resulted in lowering the amount of Mn in the second experiment than in the first experiment.

Fergus (1954) found that Kidney bean showed Mn toxic symptoms when grown on an acid soil of less then pH 5.0. The greenhouse study showed manganese ranged from 22.6 to 72.3 ppm which may not show toxicity symptoms due to acidity levels being above pH 5.0. In strongly acid soils, manganese is frequently present in toxic concentrations, and may often be one of the causes of poor yields or crop failure (Labanauskas, 1966; Brady, 1984). Leeper (1947) reported that manganese deficient soils showed manganese concentration of 21 ppm or below extractable by ammonium acetate and quinol. Therefore, the greenhouse study soil was not expected to show manganese deficiency.

Iron: Aluminum sulfate showed a higher amount of Fe in both experiments and it was highly significant above the other treatments and the control which were not significantly different (Table 7).

The high amount of Fe which resulted with the aluminum sulfate treatment may be due to low pH (Brady, 1984) and low salt (Table 7). The lower the pH, the more Fe was released.

Table 7. Iron content of Safford soil resulting from amendment applications for the first and second greenhouse experiment.

Treatment	1st Experiment Fe mg/kg soil	2nd Experiment Fe mg/kg soil
Control	9.9 a*	6.1 a*
H_2SO_4	13.8 a	7.9 a
$Al_2(SO_4)_3$	54.5 b	25.9 b
$CaSO_4$	9.1 a	4.9 a

*Means followed by same letters are not significantly different at the 0.05 level according to LSD test. Mean of 4 replications.

In the second experiment, the amount of Fe was lower than the first experiment, especially with aluminum sulfate (Table 7) which was half the amount of the first experiment. The lower amount in the second experiment may be due to higher amounts of water used (irrigation was twice a day) and shorter period of time for the experiment (4 weeks).

Wallihan (1966) reported that iron deficiency most commonly occurs in calcareous soils, poorly drained soils, and maganiferous soils. The most common condition associated with iron deficiency in plants is the presence of calcium carbonate in the soil or excessively wet soil. Brady (1984) suggested that total iron ranges in the soil from 5,000 to 50,000 ppm. The soils that were treated with aluminum sulfate may not show deficiency of iron compared to control, gypsum and sulfuric acid, which may show iron deficiency on plants.

Copper: In the first experiment, Cu was significantly the lowest when the soil was treated with aluminum sulfate (Table 8). The control, gypsum and aluminum sulfate were not significantly different from each other. The control and gypsum were higher than aluminum sulfate, and were lower than sulfuric acid which was the highest (Table 8). The control, sulfuric acid, and gypsum also were not significantly different against each other. The amounts of Cu from each sample of treated and control soil were in the same range as 48.9 to 57.45 mg/kg soil.

In the second experiment, the amounts of Cu were almost parallel to the amounts found in the first experiment but the aluminum sulfate showed lower Cu than the other treatments. Sulfuric acid and gypsum were not significantly different than the control.

Bould et al. (1953) found that soils containing more than 2 ppm of total copper did not produce deficiency symptoms in apple and pear trees. Reuther and Smith (1954) and Wander (1954) reported that toxic effects of high copper in citrus orchard soils is associated with 150 to 200 ppm of total copper in the top soil and a pH of 5.0 or less. According to Pack et al. (1953), total copper contents of surface soils varied from 2 ppm for sand to 61 ppm for a loam. Therefore, Safford soil contains copper at levels that are not toxic nor deficient to plants. That was confirmed by Brady (1984) by his suggestion that the copper range in the soils is 5 to 150 ppm.

Zinc: In both experiments, Zn showed parallel amounts resulted from all the treatments and the control (Table 9). The control and gypsum were significantly

Table 8. Copper content of Safford soil resulting from amendment applications for the first and second greenhouse experiment.

Treatment	1st Experiment Cu mg/kg soil	2nd Experiment Cu mg/kg soil
Control	51.6 a*	48.9 b*
H_2SO_4	57.5 b	49.8 b
$Al_2(SO_4)_3$	48.9 a	33.4 a
$CaSO_4$	50.2 ab	44.9 b

*Means followed by same letters are not significantly different at the 0.05 level according to LSD test. Mean of 4 replications.

Table 9. Zinc content of Safford soil resulting from amendment applications for the first and second greenhouse experiment.

Treatment	1st Experiment Zn mg/kg soil	2nd Experiment Zn mg/kg soil
Control	3.2 a*	2.7 a*
H_2SO_4	5.8 b	4.2 b
$Al_2(SO_4)_3$	20.8 c	12.5 c
$CaSO_4$	2.8 a	2.4 a

*Means followed by same letters are not significantly different at the 0.5 level according to LSD test. Mean of 4 replications.

lower than sulfuric acid which was lower than aluminum sulfate. The aluminum sulfate produced the highest concentration of extractable Zn and was significantly higher than the other three treatments.

The pH and Zn relation was inversely proportional, as the pH decreases, the amount of Zn released increased as in aluminum sulfate, followed by sulfuric acid.

In the first experiment, the Zn was higher than in the second experiment. The lower amount of Zn in the second experiment may be due to the high amount of water used as a result of irrigating twice a day and a shorter time period for the experiment to release more Zn.

The zinc range in the soil was between 2.4 to 20.8 mg/kg soil. Barnette (1936) found that 400 ppm of Zn in replaceable form was toxic to corn. Shaw and Dean (1953) reported that where Zn values of 1 ppm and less on soils of pH 7.0 or higher were found, many crops showed Zn deficiency, meanwhile with soils of pH 6.0 or lower, 2.5 ppm of Zn sufficed. Chapman (1966) reported that in most calcareous soils, 3 ppm or more of Zn was adequate where alkalinity was under 5 meq/100 g of soil. Therefore, gypsum and control may show Zn deficiency on the plants due to their ranges of 2.4 to 3.2 mg/kg soil.

pH

pH: Aluminum sulfate lowered the soil pH the most followed by sulfuric acid and gypsum, respectively. The decrease in the soil pH was significantly different in all the treatments against the control (Table 5). In general, the pH of the treatment was lower in the first experiment which may be due to the longer time than in the second experiment.

Aluminum sulfate, sulfuric acid, and gypsum, respectively, are effective chemical agents in lowering the pH of salt-affected soils.

EC of 1:1 Soil-Water Ratios and
EC of Saturation Extracts

Figure 3 shows the correlation between electrical conductivity of the 1:1 soil-water ratio and the saturation extract of 32 samples used in the greenhouse study from Safford, Arizona.

High sodium and the heavy texture of Safford soils make extraction of the saturation extract solution difficult because it is time consuming as well as requiring an extracting air suction pump. On the other hand, using a 1:1 ratio is easy in extracting soil solution for measuring the EC and using the equation of a regression to estimate the EC of the saturation extract is a valuable tool.

Figure 3 and Table 10 show saturation extract and 1:1 soil:water ratio of 32 soil samples used in both greenhouse experiments. The curve shows a relation in the form of a regression equation with a slope and an interception as follows:

$$y = mx + b \qquad (1)$$

where

y = the electric conductivity of 1:1 ratio

x = electrical conductivity of saturation extract (EC_e)

m = slope of the line

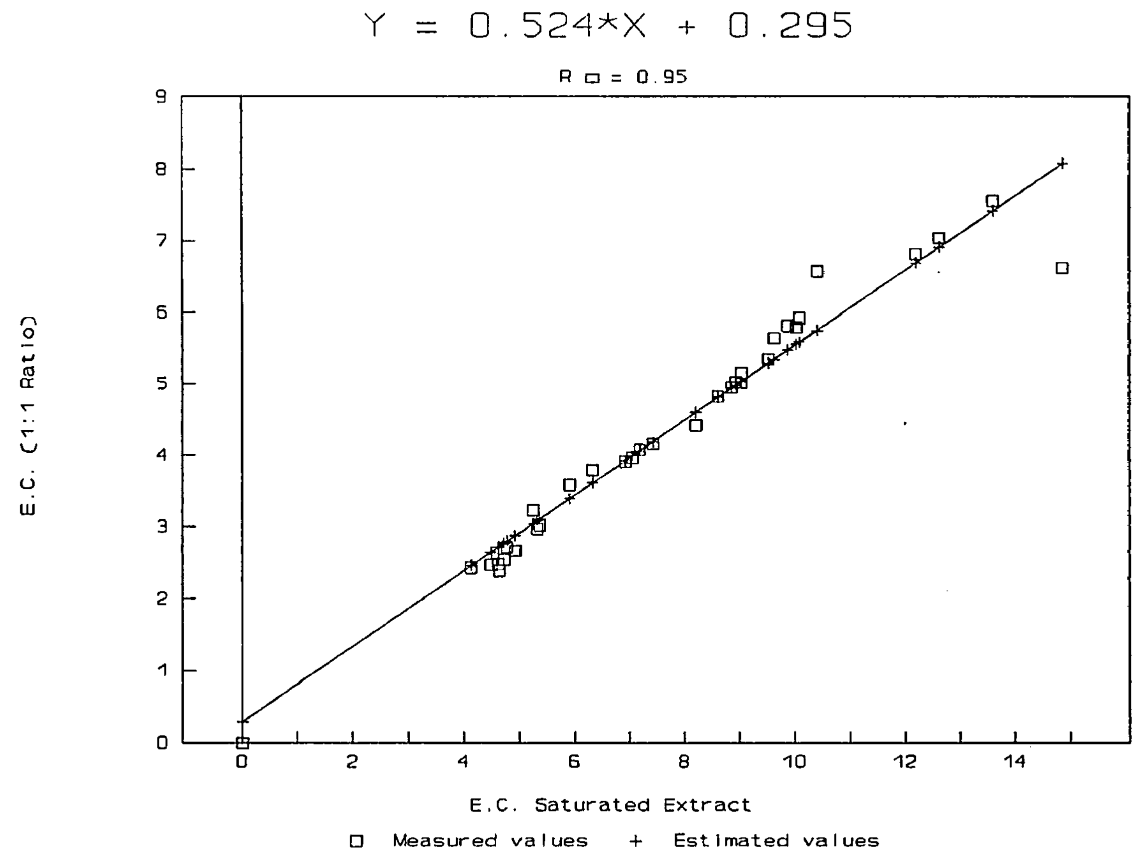

Fig. 3. Relationship of EC from saturation extracts and 1:1 soil to water ratios.

Table 10. Electrical conductivity of 1:1 soil:water and saturation extract of first and second greenhouse studies on Pima soil from Safford.

Treatment	Rep	1st Experiment dS/m		2nd Experiment dS/m	
		1:1 ratio EC	Saturation Extract	1:1 ratio EC	Saturation Extract
Control	1	7.04	12.63	3.91	6.93
	2	6.81	12.20	4.16	7.43
	3	6.62	14.86	3.97	7.06
	4	7.56	13.50	4.08	7.19
H_2SO_4	1	5.81	9.88	2.43	4.13
	2	4.95	8.86	2.71	4.78
	3	5.64	9.63	2.55	4.72
	4	5.15	9.04	2.47	4.49
$Al_2(SO_4)_3$	1	5.01	9.03	2.97	5.32
	2	4.82	8.61	2.48	4.62
	3	4.42	8.21	2.39	4.64
	4	5.02	8.94	2.67	4.93
$CaSO_4$	1	5.34	9.53	3.23	5.24
	2	5.92	10.09	3.79	6.33
	3	5.79	10.03	3.58	5.91
	4	6.57	10.41	3.02	5.36
	x	5.7794	10.3469	3.1506	5.5663
	Sd	.9095	1.9344	0.6621	1.0901

b = the y - intercept

In order to estimate the saturated extract electric conductivity the 1:1 soil:water ratio electric conductivity and applying the following equation. The equation can be used to estimate the EC of the saturation extract from 1:1 soil water ratio EC data as follows:

$$x = \frac{y - b}{m} = \textit{the electrical conductivity of the saturation extract}$$

From Figure 3, the slope of the line = 0.524 and the interception = 0.295, then

$$y = 0.524\,x + 0.295 \qquad (2)$$

or

$$x = \frac{y - 0.295}{0.524} \qquad (3)$$

For calculation, use data of 1:1 to calculate the saturation extract from equation (3).

In the first experiment, the control values of the EC were the highest in the saturation extract and 1:1 ratio followed by gypsum, sulfuric acid and aluminum sulfate, respectively. All the chemicals produced significant differences against the control in lowering the EC of the soil. Sulfuric acid and gypsum were not significantly different, also sulfuric acid and aluminum sulfate were not. Aluminum sulfate showed more effectiveness in lowering the EC of the soil than gypsum.

Sulfuric acid lowered the EC, and it was in between gypsum and aluminum sulfate in its effectiveness. Therefore, the three chemicals were effective in reducing the salt content of salt-affected soils.

In the second experiment, the EC_e was reduced the most by sulfuric acid followed by aluminum sulfate and gypsum on the saturation extract basis (Tables 10 and 11).

In the 1:1 ratio, sulfuric acid and aluminum sulfate were not significantly different but both were significantly different against gypsum and the control. Gypsum was significantly different than the control.

In the saturation extract, all three chemicals were significantly different against each other, as well as against the control in reducing the salt concentration in terms of EC in Safford soil. The three chemicals reduced the EC significantly as sulfuric acid followed by aluminum sulfate and gypsum, respectively.

Therefore, sulfuric acid and aluminum sulfate were the most effective followed by gypsum in lowering the salt content of salt-affected soil in terms of EC.

The relation of decreasing the soil pH and EC was not a straight line as in Figure 4. The pH and EC reduction by aluminum sulfate and sulfuric acid was the most followed by gypsum (Table 11).

Thus, aluminum sulfate, sulfuric acid and gypsum were effective agents in reducing the soil pH and the salt concentration in salt-affected soils.

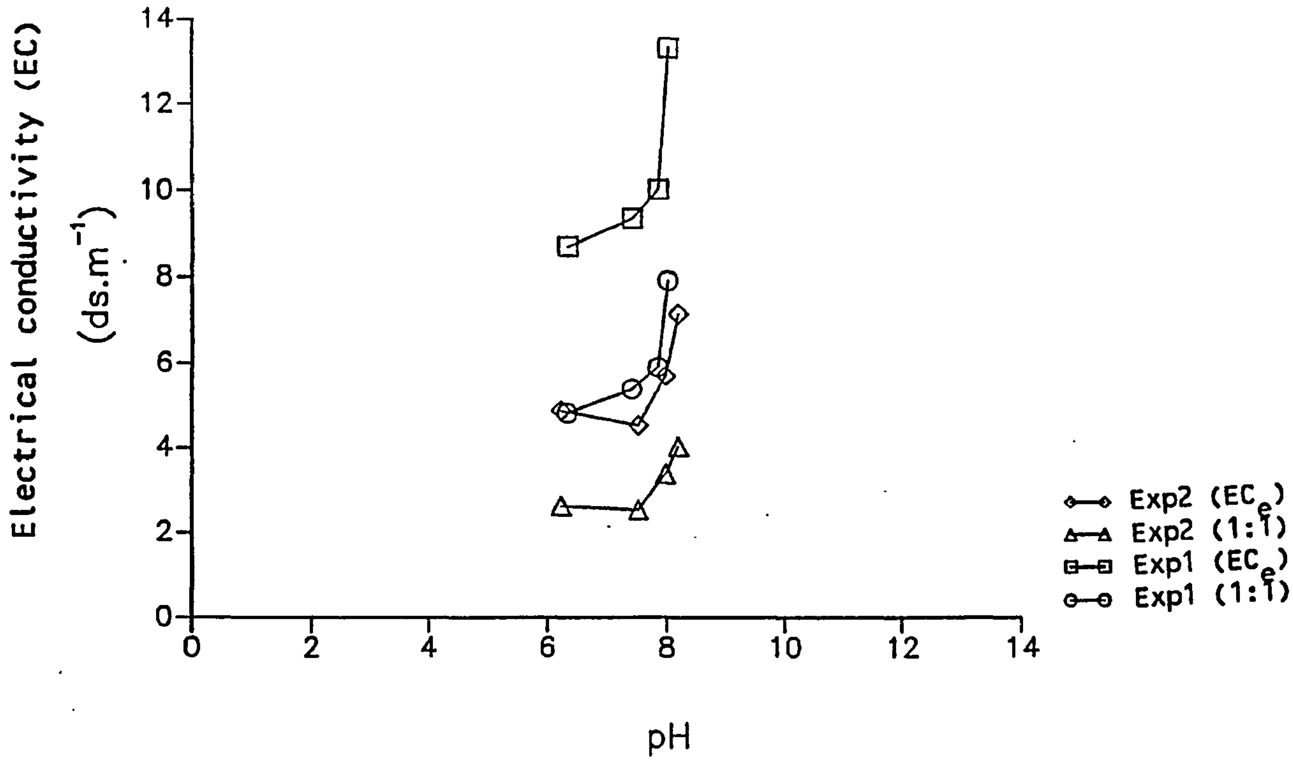

Fig. 4. The effect of the amendments on the soil pH and EC_e. Mean of 4 samples.

Table 11. The effect of the treatments on the soil electrical conductivity of 1:1 soil:water and saturation extract of first and second greenhouse studies on Pima soil from Safford.

Treatment	First Experiment		Second Experiment	
	1:1 ratio	EC_e	1:1 ratio	EC_e
Control	7.01 c*	13.33 c*	4.03 c*	7.15 d*
H_2SO_4	5.39 ab	9.35 ab	2.54 a	4.53 a
$Al_2(SO_4)_3$	4.82 a	8.70 a	2.63 a	4.88 b
$CaSO_4$	5.91 b	10.02 b	3.40 b	5.71 c

*Means followed by same letters are not significantly different at the 0.05 level according to LSD test. Mean of 4 replications.

The Field Study

Onions

Stand Counts: The two water qualities did not show any significant differences among the treatments of aluminum sulfate, aluminum sulfate II, sulfuric acid I, sulfuric acid II, and gypsum against the control.

The germination percent of the seeds was between 91 to 100% in the first and second stand counts (Table 12). The high percentage of emerged seeds indicated that anti-crust agents and water qualities had no affect on the germination rates of the onions.

Yield: The city water (fresh water) showed no significant differences among the different chemical amendments in terms of onion yields produced (Table 13).

Table 12. Stand counts resulting from application of soil amendments to control crusting for onion, Safford Agricultural Center, 1986.

Treatment	Well H_2O		City H_2O	
	Av. # of Plants	% Germination	Av. # of Plants	% Germination
Control	124.6	100	131.1	100
$Al_2(SO_4)_3$ I	123.3	99.2	121.4	97.6
$Al_2(SO_4)_3$ II	115.6	93.6	116.9	94.4
H_2SO_4 I	124.4	100	128.8	100
H_2SO_4 II	112.6	91.3	121.4	97.6
Gypsum	126.4	100	129.0	100

Means of 8 replications.

Table 13. Yields and number of bulbs of onions resulting from application of soil amendments to control crusting under two water qualities, Safford Agricultural Center, 1986.

Treatment	Well H_2O Average kg/plot	Bulbs Number	City H_2O Average kg/plot	Bulbs Number	Yield Ratios of City:Well
Control	8.83 a*	101.6	17.38 a	117.4	2.00
$Al_2(SO_4)_3$ I	10.71 b	98.3	17.62 a	100.6	1.65
$Al_2(SO_4)_3$ II	11.95 bc	106.6	16.64 a	103.4	1.40
H_2SO_4 I	12.86 c	109.4	18.55 a	116.3	1.46
H_2SO_4 II	13.29 c	105.7	20.52 a	125.7	1.55
Gypsum	13.60 c	118.6	18.24 a	124.4	1.33

*Means followed by same letters are not significantly different at 0.05 level according to LSD test. Mean of 8 replications.

In the case of well water, all chemical treatments showed significant yield increases compared to the control. Gypsum showed the highest onion yield followed by sulfuric acid II, sulfuric acid I, and aluminum sulfate II, respectively, and they were not significantly different from each other. Aluminum sulfate I and II were not significantly different between each other but were greater than the control (Table 13).

Due to the field plot design, a direct statistical comparison of well water versus city water could not be made.

The yields of onion in case of city water were higher than the same treatment in case of well water. The ratios of yields with fresh water to well water were from 1.33 to 2.00 times that of the same treatment (Table 13). The calculated ratios between well and city water showed that the high quality water is an important factor in increasing yield whether using chemicals or not on salt affected soils. When using city water, the yield can be doubled without the use of soil amendments. The chemical treatment showed effectiveness in increasing onion yields and decreasing the salt effect with well water. All the chemical agents showed a significant increase in yields over the control.

In conclusion, those chemicals showed no effectiveness in seeds germinated in case of salt-affected soil irrigated with low salt city water showed increase in the yield with sulfuric acid II, followed by sulfuric acid I and gypsum, respectively, but they were significantly greater than the control.

Chili Peppers

Stand Counts: The second stand count showed some significant differences. Gypsum showed the highest amount of seed germinated with the well water followed by sulfuric acid and polymer of aluminum sulfate. Sulfuric acid and the polymer produced the same stand counts and they were not significantly different against the gypsum (Table 14). Aluminum sulfate-polymer, control, and aluminum sulfate were a low-stand count group and were not significantly different. Gypsum, sulfuric acid, and the polymer were high-stand count groups. The stand count was significantly different between the two groups. Therefore, gypsum is considered to be the most effective in increasing the seed emergence of the chili pepper and decreasing the salt affects followed by sulfuric acid and the polymer of aluminum sulfate in salt-affected soil that was irrigated with high salted water.

The control, sulfuric acid, aluminum sulfate-polymer and aluminum sulfate were not significantly different in increasing the emergence of seeds that were irrigated with low salt city water. On the other hand, the polymer and gypsum were the highest in increasing the stand counts and were not significantly different against the control (Table 14).

Seed emergence with the same chemical with well water was less than the seeds germinated with city water. The low salt city water produced stand counts between 1.4 to 3.59 times greater than stand counts produced by high salt well water. Therefore, the less salt in water, the more seeds will germinate on the same type of salt-affected soils (Table 14).

Table 14. Stand counts resulting from application of soil amendments to control crusting for chili peppers under two water qualities, Safford Agricultural Center, 1986.

Treatment	Well H_2O	City H_2O	Stand Count Ratio City:Well
	Av. seedlings/plot		
Control	4.63 a*	16.65 ab*	3.59
Boligrow (1000 kg/ha)	4.50 a	12.63 a	2.81
Boligrow + polymer (1000 kg/ha)	5.00 a	13.38 a	2.63
Polymer of $Al_2(SO_4)_3$ (500 kg/ha)	10.63 b	22.00 b	2.07
H_2SO_4 (500 kg/ha)	10.63 b	14.88 a	1.40
$CaSO_4$ (830 kg/ha)	13.00 b	21.38 b	1.64

* Means followed by same letters are not significantly different at 0.05 level according to LSD test. Mean of 8 replications.

Yield: The chemical amendments with city water did not result in significant differences in pepper yield over the control (Table 15). Using the chemicals showed no impact to increase yields of the chili peppers irrigated with low-salted water in salt-affected soils.

The polymer of aluminum sulfate, sulfuric acid, and gypsum produced significantly higher pepper yields over the control under the high-salted well water in salt-affected soils (Table 15). The Boligrow and Boligrow with polymer mix were not significantly different than the control.

Table 15. Yields resulting from application of soil amendments to control crusting for chili pepper under two water qualities, Safford Agricultural Center, 1986.

Treatment	Well H_2O	City H_2O	Yield Ratio City:Well
	kg/plot		
Control	.71 a*	3.25 a*	4.37
Boligrow (1000 kg/ha)	.82 a	2.59 a	3.13
Boligrow + polymer (1000 kg/ha)	.96 a	2.21 a	2.30
Polymer of $Al_2(SO_4)_3$ (500 kg/ha)	2.18 b	2.92 a	1.33
H_2SO_4 (500 kg/ha)	2.04 b	2.70 a	1.32
$CaSO_4$ (830 kg/ha)	1.87 b	3.23 a	1.70

*Means followed by same letters are not significantly different at 0.05 level according to LSD test. Mean of 8 replications.

The polymer of aluminum sulfate, sulfuric acid and gypsum were effective in increasing chili pepper yields in salt-affected soil irrigated with high salt well water of high EC.

The use of high quality water can make a difference in the yield of chili pepper. Table 15 shows that the ratio of the yield of low salt city water to the well water was between 1.32 to 4.37 times. The control was affected the most by the water qualities, as the ratio of city to well water was 4.37. Thus, using high quality water of low salt content can be a substitute for the use of the chemicals to increase the yield of chili peppers in salt affected soil. On the other hand, using the amendments can help improve the soil, especially in cases of high salt water and salt-affected soil.

Tomatoes

Stand Counts: Stand Counts with well water in the, the aluminum sulfate II was the lowest followed by sulfuric acid II, aluminum sulfate I, sulfuric acid I, control and gypsum, respectively (Table 16). Aluminum sulfate I, sulfuric acid I and II were not significantly different but they were significantly lower than the control which was not significantly different from gypsum. Both the control and gypsum showed the highest stand counts with high salt well water. Aluminum sulfate II significantly lowered the stand counts more than any of the other soil amendments or the control.

Gypsum is the best in helping increase tomato seeds to emerge in salt-affected soil irrigated with high salt water.

With low salt city water stand counts, gypsum was the highest but was not significantly different than sulfuric acid I and the control. Sulfuric acid I, aluminum sulfate I and sulfuric acid II lowered the stand counts, respectively, and were not significantly different over the control. Aluminum sulfate II was the lowest in the stand count followed by sulfuric acid II and the two treatments were not significantly different.

With low salt water and salt-affected soil, gypsum is considered to be more effective in increasing the tomato seed emergence stands than the other amendments.

Table 16. Stand counts resulting from soil amendment application to control crusting for tomatoes under two water qualities, Safford Agricultural Center, 1986.

	Well H_2O	City H_2O
Treatment	Seedlings/plot	
Control	61.1 cd*	49.1 bc*
Boligrow I	40.5 bc	38.6 b
Boligrow II	16.6 a	15.3 a
H_2SO_4 I	44.4 bc	53.1 bc
H_2SO_4 II	34.1 b	30.6 ab
$CaSO_4$	69.3 d	66.1 c

*Means followed by same letters are not significantly different at 0.05 level according to LSD test.

Yields Using Well Water: Aluminum sulfate II resulted in the lowest tomato yield, which was significantly lower than the control (Table 17). Sulfuric acid I, aluminum sulfate I, and sulfuric acid II, respectively, arithmetically lowered the tomato yields but they were not significantly different compared to the control. Gypsum increased the yield significantly over the other amendments but the increase against the control was not significant.

Yields Using City Water: Gypsum increased the yield more than the other chemical agents but was not significantly different against the control and the other amendments except for aluminum sulfate II.

Table 17. Yields resulting from soil amendment applications to control crusting for tomatoes under two water qualities, Safford Agricultural Center, 1986.

Treatment	Well H_2O	City H_2O	Ratio
	kg/plot		City:Well
Control	7.87 bc*	12.76 b*	1.62*
Boligrow I (1000 lb/a)	6.77 b*	11.12 ab*	1.64*
Boligrow II (1000 lb/a)	3.77 a*	6.76 a*	1.79*
H_2SO_4 I (500 lb/a)	7.18 b*	13.89 b*	1.93*
H_2SO_4 II (500 lb/a)	5.74 ab*	12.04 ab*	2.10*
$CaSO_4$ (830 lb/a)	10.35 c*	14.42 b*	1.39*

*Means followed by same letters are not significantly different at 0.05 level according to LSD test. Mean of 8 replications.

Aluminum sulfate II reduced the yield significantly against the control and was not significantly different against the aluminum sulfate I.

Gypsum was the only chemical that helped in increasing tomato yield with city water or well water in salt-affected soil despite its non-significance against the control.

The city water showed a substantial increase in the tomato yields compared to the well water. For the same treatment, the quality of the city water made the difference as the increases ranged between 1.39 to 2.1 times the yields with the high salt well water (Table 17). Therefore, the use of high quality water (low in salts) seems to be more important in increasing the yields of tomatoes in salt-affected soils.

The Supplementary Field Study

The supplementary study was a simple variety trial with tomatoes and peppers tested under field conditions at Safford. Thus no statistical analysis was made due to the lack of replications.

Tomatoes

The production of Beefsteak tomato was the highest under salt irrigation water followed by Saladmaster, Pearson, Columbia and Rutgers, respectively (Table 18).

Under low salt city irrigation water, Beefsteak tomato gave the highest yield followed by Columbia, Pearson, Saladmaster and Rutgers, respectively. The production of the varieties was close to each other except Rutgers which was lowest in production.

The yield was greater with low salt city water than with high salt well water for the same variety. The production ratio under city water to well water of each variety was 1.55 to 3.39 times (Table 18).

Therefore, the higher the ratio, the more sensitivity the variety will have to the salts. Columbia showed 3.39:1 city water to well water production which may be an indication of high sensitivity of this variety to the salts in the well water. Rutgers tomato produced the least yield under both water qualities and its increase from well water to city water was the least. Therefore, Rutgers variety may not be suitable for tomato production in salt-affected soil and the water quality compared with the other varieties under Safford conditions.

Table 18. Yields and yield ratios of tomato varieties grown under two water qualities, Safford Agricultural Center, 1986.

Tomato Varieties	Well H_2O	City H_2O	Ratio
	kg/variety/row		City:Well
Salad Master	12.43	22.93	1.84
Beefsteak	15.95	32.22	2.02
Pearson	10.42	24.61	2.36
Columbia	7.28	24.69	3.39
Rutgers	5.63	8.74	1.55

Note: Each row is 10 m^2. Therefore, the production is equal to tons per hectare. No statistical analysis was conducted.

From the ratio and the increase of production, Beefsteak and Saladmaster were the best in case of high salt well water. In case of low salt city water, Beefsteak was the best in production followed by Columbia, Pearson and Saladmaster which are suitable for the salt-affected soil of Safford.

Peppers

In the screening of the pepper varieties, Jalapino, Anaheim and New Mexico 6-4 were the highest in yields, respectively, with California Wonder and Libyan peppers the lowest in yields under high salt well water (Table 19).

Under low salt city water, Jalapino, California Wonder, and New Mexico 6-4, respectively, were higher in yield than Anaheim and Libyan peppers (Table 19).

The yield ratio of city to well water showed city water produced remarkable high yields of California Wonder as compared to well water. Jalapino and New

Table 19. Yields and yield ratios of various pepper varieties using two water qualities, Safford Agricultural Center, 1986.

Pepper Varieties	Well H_2O	City H_2O	Ratio City:Well
	kg/variety/row		
Jalapino	7.99	12.63	1.58
New Mexico 6-4	6.76	10.48	1.55
Libyan	2.33	1.02	.44
Anaheim	7.36	2.33	.32
California Wonder	2.39	12.44	5.21

Note: Each row is 10 m^2. Therefore, the production is equal to tons per hectare. No statistical analysis was conducted.

Mexico 6-4 showed 1.58 and 1.55 ratio of city water to well water, respectively, therefore, the lower the content of salt in the water, the more production will result.

In conclusion, under the condition of using well water, Jalapino, Anaheim and New Mexico 6-4 are suited for the Safford area. Also in condition of using low salt city water, Jalapino, California Wonder, and New Mexico 6-4 can be used to produce high yields for salt-affected soil. Nevertheless, these results are based on one season, therefore, variety trials should be conducted over a number of years in order to have a range of climatic conditions for a given area to recommend a certain variety in a particular area.

The Libyan and Anaheim peppers did not do well under low salt city water and may not be considered for the Safford area.

CONCLUSIONS

In the greenhouse study, aluminum sulfate was considered to be more effective followed by sulfuric acid and gypsum, respectively, in reducing the soil pH. The three chemicals significantly reduced the pH against the control.

Electrical conductivity was decreased effectively and significantly by sulfuric acid and aluminum sulfate followed by gypsum compared to the control.

The penetrometer index showed that the crusting strength was reduced significantly by sulfuric acid, gypsum, and aluminum sulfate, respectively, against the control.

Seed emergence studies showed that sulfuric acid and gypsum were the most significant and effective in increasing the number of seeds germinated compared with aluminum sulfate and the control.

The elemental analyses of surface soils were as follows:

The extractable Al was very low and no differences among the chemicals and the control were found.

Sulfuric acid, gypsum and the control showed no significant difference in DTPA extractable Fe. Aluminum sulfate was the more effective in increasing Fe than the other chemicals which may be a result of reducing the soil pH to the range at which the Fe was released from the soil.

Gypsum lowered the DTPA extractable Mn released, but the control, sulfuric acid and aluminum sulfate were not significantly different in the first experiment. In the second experiment, aluminum sulfate released the highest amount followed by sulfuric acid and the control. The gypsum lowered the Mn released as compared to the control. The high amount of Mn released by aluminum sulfate may be a result of low pH which was lower than in the first experiment.

Aluminum sulfate was the most effective and significant in increasing DTPA extractable Zn than sulfuric acid, gypsum and the control. Aluminum sulfate showed four times more Zn released than that released by sulfuric acid which was significantly higher than gypsum and the control. Gypsum significantly increased the DTPA extractable Zn compared with the control.

None of the chemicals showed a significant increase in DTPA extractable Cu over the control. Aluminum sulfate lowered the available Cu, and sulfuric acid showed non-significant increases which may be due to the fast reaction of the acid with soil. The pH had no effect on Cu released.

During the greenhouse study, the soil showed less cracks with sulfuric acid, gypsum and aluminum sulfate, respectively, than the control.

In the stand counts of the field study, tomatoes produced more seedlings when treated with gypsum with both city and well water. The least response was with Boligrow II and the high rate of sulfuric acid. With the high rates of acid and aluminum sulfate, excess salts accumulated on the surface above the seed and caused burning of the seeding and loss of stand. Yields were also higher with gypsum when irrigated with well water and lowest with acid and Boligrow. With city water, gypsum also produced the highest yield, followed by the low rate of sulfuric acid. Both

Boligrow treatments produced low yields. The city water produced higher yields than well water with all the chemicals as the yield ratio of city water to well water ranged between 1.39 to 2.09. Therefore, the water quality (low salts) was more important in producing high tomato yields than using chemicals.

Onions did not show any response to amendment applications for either water with respect to stand counts. With well water, there was a significant difference with gypsum and sulfuric acid I and II producing the highest yields. There was no significant effect of the amendments when city water was used. Therefore, using the sulfur containing chemicals decreased the salt affect of the soil and irrigation water as a result, the onion yield increased significantly. Also, the yield ratios of city to well water of the same treatment ranged between 1.33 to 2.0. Therefore, besides the important rate of high quality water for producing high yield, the chemical agents that were used were important in increasing the yield significantly with well water.

Chili peppers responded to the amendments in the case of well water but not for city water. Stand counts were highest for gypsum, sulfuric acid and Boligrow polymer, with yields following the same pattern. With the city water, all stands were relatively low, but the same amendment produced the higher stand compared with well water. No yield effects were found with the city water. Therefore, using Boligrow polymer, sulfuric acid and gypsum were important in increasing the chili pepper yield with well water.

LIST OF REFERENCES

Agassi, M., I. Shainberg, and J. Morin. 1981. Effect of electrolyute concentration and soil sodicity on infiltration rate and crust formation. Soil Sci. Soc. Am. J. 45:848-851.

Alawi, B.J. 1977. Effect of irrigation water quality, sulfuric acid and gypsum on plant growth and on some physical and chemical properties of Pima soil. Ph.D. Dissertation. University of Arizona, Tucson.

Alawi, B.J., J.L. Stroehlein, E.A. Hanlon, Jr., and F. Turner, Jr. 1980. Quality of irrigation water and effects of sulfuric acid and gypsum on soil properties and sudangrass yields. Soil Sci. 5:315-319.

Barnette, R.M. 1936. The occurance and behavior of less abundent elements in soils. Florida Univ. Agr. Exp. Sta. Ann. Rep. 1936.

Botkin, C.W. 1933. The effects of acidifying amendments on impermeable soil. New Mexico Agric. Exp. Stn. Bull. 210.

Bould, C., D.J. Nicholas, J.A.H. Tolhurst, and J.M.S. Potter. 1953. Copper deficiency of fruit trees in Great Britain. J. Hort. Sci. 28:268-277.

Bower, C.A. 1959. Chemical amendments for improving sodium soils. USDA Agric. Information Bull 195. Washington, D.C.

Bower, C.A., L.R. Swarner, A.W. Marsh, and F.M. Tileston. 1951. The improvement of an alkali soil by treatment with manure and chemical amendments. Agric. Exp. Stn. Oregon State Univ. Bull 22. Corvallis, OR.

Brady, N.C. 1984. The nature and properties of soils. 9th Edition. MacMillan Pub. Co., Inc.. New York.

Cates, R.L., Jr., V.A. Haby, E.O. Skogley, and H. Ferguson. 1982. Effectiveness of by-product sulfuric acid for reclaiming calcareous, saline-sodic soil. J. Environ. Qual. 11:2.

Chapman, H.D. 1966. Zinc. In H.D. Chapman (ed.) Diagnostic Criteria for Plants and Soils. Univ. of California Division of Agricultural Sciences. Riverside, California.

Christensen, P.D., and P.J. Lyerly. 1954. Yields of cotton and other crops as affected by application of sulfuric acid in irrigation water. Soil Sci. Soc. Am. Proc. 18:433-436.

Dennis, R.E., and B.B. Wudiri. 1976. Use of phosphoric and sulfuric acid to reduce soil crusting and improve emergence of sugarbeet seedlings. IN Report on sugar beets. Coop. Ext. Agric. Exp. Stn., Univ. of Ariz., p. 39.

Dutt, G.R., R.W. Terkeltaub, and R.S. Rauschkolb. 1972. Prediction of gypsum and leaching requirements for sodium-affected soils. Soil Sci. 114:93-99.

Fannin's Farm Facts. 1954. Soil amendment with sulfuric acid. Bull. 44-54. Phoenix, AZ (mimeo).

Fergus, I.F. 1954. Manganese toxicity in an acid soil. Queensland J. Agr. Sci. 11:15-27.

Fireman, M., C.A. Morgan, and G.O. Baker. 1950. Characteristics of saline and alkali soils in the Emmett Valley area Idaho. Agric. Exp. Stn. Univ. Idaho, Moscow, Research Bull. 17.

Fuller, W.H., and H.E. Ray. 1963. Gypsum and sulfur-bearing amendments for Arizona soils. Coop. Ext. Ser. and Agric. Exp. Stn., Univ. Ariz. Bull. A-27.

Gardener, R. 1945. Some soil properties related to sodium salt problems in irrigated soils. USDA. Washington, D.C. Tech. Bull 902.

Gupta, B.R., and P.D. Bajpai. 1977. Effect of some inorganic ameliorants on reclamation and phosphorus availability in salt-affected soils. Indian J. Agric. 11:97-103.

Johnson, R.C., and J.B. Law. 1967. Controlling soil crusting in sugar-beet fields by applying concentrated sulfuric acid. J. Am. Soc. Sugarbeet Technol. 14:615-618.

Johnston, W.W., and W.L. Powers. 1924. A progress report of alkali land reclamation investigations in Eastern Oregon. Oregon Agric. Exp. Stn. Bull 210.

Kadry, L.T. 1978. Sulfur Institute Seville Symposium. FAO Report.

Kelley, W.P., and A. Arany. 1928. The chemical effect of gypsum, sulfur, iron sulfate, and alum on alkali soil. Hilgardia 3:393-420.

____________, and E.E. Thomas. 1928. Reclamation of the Fresno type of black-alkali soil. Univ. of California. Berkeley Bull 455.

Kemper, W.D., and D.E. Miller. 1974. Management of crusting soils: Some practical possibilities. Ariz. Agric. Exp. Stn. Tech. Bull 214.

____________, and L. Noonan. 1970. Runoff as affected by salt treatment and texture. Soil Sci. Soc. Am. Proc. 34:126-130.

Labanauskas, C.L. 1966. Manganese. In H.D. Chapman (ed.), Diagnostic Criteria for Plants and Soils. Univ. of California Div. of Agr. Sci. Riverside, California.

Leeper, G.W. 1947. The forms and reactions of magnanese in the soil. Soil Sci. 63:79-94.

Little, T.M. 1960. Experimental methods for extension workers. Agric. Ext. Serv., Univ. of California, Davis.

Loveday, J. 1975. The use of sulfur and its compounds in soil amendment. P. 163-171. In K.D. Mclachlan (ed.) Sulfur in Australian Agric. Sydney, Univ. Press. Sydney.

Mathers, A. 1970. Effect of ferrous sulfate and sulfuric acid on grain sorghum yield. Agron. J. 5:555-556.

McCormick, J.A., and E.A. Naphan. 1952. Improving saline and alkali soils in Nevada. Univ. of Nevada Agric. Exp. Stn. and USDA Soil Conservation Service Cooperating. Stn. Circular 1.

McGeorge, W.T. 1945. Gypsum, a soil corrective and soil builder. Univ. of Arizona Agric. Exp. Stn., Bull. 200.

____________, E.L. Breaseals, and A.M. Bless. 1952. The salinity problem - Safford Experiment Farm Field Experiments. Univ. of Arizona Agric. Exp. Stn. Techn. Bull. 124.

McIntyre, D.S. 1958. Permeability measurements of soil crusts formed by raindrop impact. Soil Sci. 85:185-189.

Miyamoto, S, and J.L. Stroehlein. 1986. Sulfuric acid affects on water infiltration and chemical properties of alkaline soils and water. Am. Soc. of Agric. Eng. 219:1288-1296.

____________, H.L. Bohn, J,. Ryan, and M.S. Yee. 1974. Effect of sulfuric acid and sulfur dioxide on aggregate stability of calcareous soils. Soil Sci 118:299-303.

____________, R.J. Prather, and J.L. Stroehlein. 1975a. Sulfuric acid and leaching requirements for reclaiming Na-affected calcareous soils. Plant Soil. 43:573-585.

____________, R.J. Prather, and J.L. Stroehlein. 1975b. Sulfuric acid for controlling calcite precipitation. Soil Sci. 120:264-271.

____________, J. Ryan, and H.L. Bohn. 1973. Penetrability and hydraulic conductivity of dilute sulfuric acid solutions in selected Arizona soils. Proc. Am. Water Resource Assn. Ariz. Section p. 291-298.

Mohamed, E.T.Y. 1972. The effect of various sulfur compounds on infiltration rates of selected soils. Ph.D. Dissertation, Univ. of California, Riverside.

O'Connor, G.A., and V. Lee. 1978. Effects of sulfuric acid on soil permeability and irrigation water quality. New Mexico State Univ. Agric. Exp. Stn. Research Rep. 361.

Olson, R.V. 1950. Effects of acidification, iron oxide addition, and other soil treatments on sorghum chlorosis and iron absorption. Soil Sci. Soc. Am. Proc. 15:97-101.

Overstreet, R., J.C. Martin, and H.M. King. 1951. Gypsum, sulfur, sulfuric acid for reclaiming an alkali soil of the Fresno series. Hilgardia. 21:113-127.

______________, ____________________, R.K. Schulz, and O.D. McCutcheon. 1955. Reclamation of an alkali soil of the Hacienda series. Hilgardia 24:53-68.

Pack, M.R., S.J. Toth, and F.E. Bear. 1953. Copper status of New Jersey soils. Soil Sci. 75:433-441.

Page, A.L., R.H. Miller, and D.R. Keeney. 1982. Methods of soil analysis Part 2 - chemical and microbiological properties. 2nd Ed. Soil Sci. Soc. of Am., Madison, Wis.

Pearson, G.A. 1960. Tolerance of crops to exchangeable sodium. USDA. Agric. Information Bull 216.

Petrosian, G.P. 1974. Saline soils retreat. International Congress of Soil Science. Moscow.

Post, D.F., D.M. Hendricks, and J.M. Hart. 1977. Soils of the University of Arizona Experimental Station: Safford. Agric. Eng. and Soil Sci. Series 72-1. The Univ. of Ariz.

Powers, W.L. 1946. Reclamation and use of alkali soils. Oregon State Univ. Agric. Exp. Stn. Tech. Bull. 10. Corvallis.

Prather, R.J., J.O. Geortzen, J.D. Rhoades, and H. Frenk. 1978. Efficient amendment use in sodic soil reclamation. Soil Sci. Soc. Am. J. 42:782-786.

Rasmussen, W.W., D.P. Moore, and L.A. Alban. 1972. Improvement of a solonetzic (slick spot) soil by deep plowing, subsoiling and amendments. Soil Sci. Soc. Am. Proc. 36:137-142.

Reuther, W., and P.F. Smith. 1954. Symposium: Minor elements in relation to soil factors. Toxic effects of accumulated copper in Florida soils. Soil Sci. Soc. Florida Proc. 14:17-23.

Ryan, J. , S. Miyamoto. and H.L. Bohn. 1973. Effect of sulfuric acid in high sodium irrigation water on the growth of peas and beans in calcareous soils. Soil Sci. Soc. Am. Proc. 65:999-1000.

___________, S. Miyamoto, and J.L. Stroehlein. 1974. Solubility of manganese, iron, and zinc as affected by application of sulfuric acid. Plant Soil. 40:421-427.

___________, and J.L. Stroehlein. 1973. Use of sulfuric acid on phosphorus deficient Arizona soils. Progressive Agric. Arizona 25(6):11-13.

Schoonover, W.R. 1953. Testing and reclaiming alkali soils. Am. Potash. Institute Inc., Washington, D.C. Reprint FF-10-53.

_______________, M.M. Elgabaly, and M.N. Hassan. 1957. A study of some Egyptian saline and alkali soils. Hilgardia. 26:565-596.

Shaw, E., and L.A. Dean. 1952. Use of dithizone as an extractant to estimate the zinc nutrient status of soils. Soil Sci. 83:341-347.

Stroehlein, J.L. 1978. Potential uses of sulfur compounds for soil and water management. The use of sulfur containing products in agriculture. Seville Symposium 1978.

______________, S. Miyamoto, and J. Ryan. 1978. Sulfuric acid for improving irrigation waters and reclaiming sodic soils. Univ. of Arizona, Dept. of Soils, Water and Eng. Series 78-5, Tucson.

______________, T.A. Yahia, and D.A. Pennington. 1980. Use of anhydrous ammonia and sulfuric acid in irrigation water. Agric. Engr. Soil Sci. Series 80-1, pg. 1-2.

______________, and D.A. Pennington. 1986. Use of sulfur compounds for soil and irrigation water treatments. Crop Sci. Soc. of Am. 16:435-454.

Tavassoli, A. 1980. Soil nutrient availability during reclamation of salt-affected soil. Ph.D. Dissertation. The Univ. of Arizona, Tucson.

Tisdale, S.L. 1970. The use of sulfur compounds in irrigated arid land agriculture. Sulfur Institute J. 6:2-7.

USDA Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dept. of Agric. Handbook, 60.

Velasco, I. 1981. Improving the sodic soils of Spain. Sulfur Agric. 5:2-4.

Wallihan, E.F. 1966. Iron. In H.D. Chapman (ed.), Diagnostic Criteria for Plants and Soils. Univ. of California Div. of Agric. Sci. Riverside, California.

Wander, I.W. 1954. The total manganese, copper, and zinc content of soils used for citrus production in Florida. Soil Sci. Soc. Florida Proc. 14:27-33.

Yacoub, M.M. 1984. Effect of sulfur-containing amendments on manganese and phosphorous availability in soils. M.S. Thesis, The Univ. of Arizona, Tucson.