

# Evaluation of An Acid Soil Conditioner in An Irrigated Cotton Production System

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## Abstract

*A single field study was conducted on a sodium-affected soil at the University of Arizona's Maricopa Agricultural Center (MAC) in 1998. NuCotn<sup>0</sup> 33B was dry planted and watered-up on 5 May 1998. Two treatments were evaluated; treatment 1 received no acid and treatment 2 received water-run acid applications. The acid used in this evaluation was sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). The acid was applied at approximately 11 gallons acid/acre at each scheduled irrigation throughout the entire growing season. All other agronomic inputs and decisions were uniformly applied to both treatments in the same manner throughout the season. The experiment was arranged in a randomized complete block design with two treatments and six replications. Significant differences were found among the two treatments in terms of plant growth and soil water content (P<0.05). Lint yields were significantly different (P=0.0013) with the check having the highest yield.*

## Introduction

Sodic soils caused by irrigation with marginal to poor quality water are a continual and increasing problem in the agricultural regions of the desert Southwest. This problem is one that is best described as an accumulative effect where the sodium (Na) levels become a problem over time via the continual addition of Na from the irrigation water and the inability to adequately leach. Soils of this type have long been the focus of specific management techniques to control and manage Na problems caused by marginal and poor quality irrigation water.

The effects of high amounts of Na in a soil can have very detrimental effects to seedling emergence as well as toxicity levels that vary by crop species. By definition, a sodic soil is one that has an exchangeable sodium percentage (ESP) of 15% or more (U.S. Salinity Laboratory Staff, 1954). They can also be characterized as having a Na absorption ratio (SAR<sub>e</sub>) from a saturated soil extract of 13 or greater.

Soils high in Na are inclined to have water penetration and infiltration problems due to the dispersion of clay particles within the soil (Yousaf et.al. 1987; Amezketa and Aragues, 1995). Dispersion of clay particles allows them to be transported into pore spaces that were previously available for water penetration and infiltration. Sealing of soil pores can produce a crusting problem that can inhibit seedling emergence and growth. Sodic conditions cannot be corrected with additional irrigation (leaching) applications alone, in fact, the problem may be exacerbated by applying additional water, particularly if it is high in Na. Calcium (Ca) and magnesium (Mg) are the primary elements that contribute to soil flocculation while Na causes dispersion in a soil. Sodium causes dispersion of a soil because of its large hydrated radius, as compared to Ca<sup>2+</sup>, Mg<sup>2+</sup> and potassium (K<sup>+</sup>). The large hydrated radius of Na<sup>+</sup> essentially forces the clay particles apart leading to a dispersed soil condition.

An example of a problem that can be developed associated with irrigation is the increase in pH of the irrigation water as a result of the introduction of anhydrous ammonia (liquid NH<sub>3</sub>) nitrogen (N) fertilizer into the irrigation water. The increase in pH can cause the flocculating cations, Ca<sup>2+</sup> and Mg<sup>2+</sup>, to precipitate with bicarbonate (HCO<sub>3</sub><sup>-</sup>) and carbonate (CO<sub>3</sub><sup>2-</sup>) leaving soluble Na<sup>+</sup> in the irrigation water. The application of this type of N-fertilizer has the potential to effectively raise the SAR of the irrigation water. This, in turn, can cause a sodic soil condition that can be difficult to manage. The use of poor quality irrigation water can also be a major culprit in the development of a sodic soil, without any addition of anhydrous ammonia N fertilizer into the irrigation water. Poor quality irrigation water is often the only source of irrigation water for some farms in the desert Southwest.

There are several traditional treatments used to correct sodicity problems in soils. One approach involves the addition of elemental sulfur (S). Elemental S, when oxidized by soil microbes and combined with water, reacts to form sulfuric acid ( $\text{H}_2\text{SO}_4$ ), which reacts with naturally occurring calcium carbonate ( $\text{CaCO}_3$ ), releasing “free”  $\text{Ca}^{2+}$ . This  $\text{Ca}^{2+}$  in the soil solution can then exchange for  $\text{Na}^+$  in the form of sodium sulfate ( $\text{Na}_2\text{SO}_4$ ), which can be leached from the soil. Sulfuric acid can also be added to the irrigation water or soil directly. When adding elemental S or  $\text{H}_2\text{SO}_4$ , not only can  $\text{Na}^+$  be converted to a leachable form, the pH of the water or soil can also be lowered.

Another common treatment of sodic soils is the use of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). Gypsum can increase the  $\text{Ca}^{2+}$  level in the soil that can then exchange with the  $\text{Na}^+$  creating  $\text{Na}_2\text{SO}_4$ , which can be leached from the soil. This addition of  $\text{Ca}^{2+}$  serves to lower the SAR and contributes to the exchange and leaching of soil  $\text{Na}^+$ .

Extensive studies conducted worldwide on arid soils have shown that there is a consistent relationship between the effects of SAR, pH, and electrolyte concentration on relative hydraulic conductivity ( $K_s$ ) and clay dispersion (Suarez et al., 1984). It has also been demonstrated that the plant available  $\text{Ca}^{2+}$  is generally independent of the amount of  $\text{CaCO}_3$  naturally present in the soil (Flocker and Fuller, 1956).

The objective of this study was to use  $\text{H}_2\text{SO}_4$  in a naturally calcareous soil in an attempt to alleviate some of the problems that have been exhibited due to high Na accumulations in the soil and high Na and  $\text{HCO}_3^-$  levels in the irrigation water. When the  $\text{H}_2\text{SO}_4$  is added to the irrigation stream it is intended to reduce the pH of the water and reduce the precipitation of  $\text{CaCO}_3$  and  $\text{MgCO}_3$ . The  $\text{H}_2\text{SO}_4$  is also intended to release  $\text{Ca}^{2+}$  from the natural  $\text{CaCO}_3$  in the soil and replace  $\text{Na}^+$  on the soil cation exchange sites. The soil solution  $\text{Na}^+$  can then combine with the  $\text{SO}_4^{2-}$  and be leached from the soil profile as  $\text{Na}_2\text{SO}_4$ .

## Materials and Methods

The field experiment was planted with an Upland cotton (*Gossypium hirsutum* L.; variety DP NuCotn™ 33B) on a calcareous Casa Grande sandy loam soil [fine-loamy, mixed, hyperthermic Typic Natrargid (reclaimed)] at the Maricopa Agricultural Center (MAC) on 5 May 1998. The experiment was dry planted and watered-up on the same day. The experimental structure consisted of two treatments (with and without  $\text{H}_2\text{SO}_4$ ) arranged in a randomized complete block design with six replications. Plots consisted of twelve, 40-inch rows, extending the full length of the irrigation run (approximately 650 feet from head to tail). A bulk pre-season soil sample was collected from the study area on 4 April 1998 and post-season soil samples for each treatment were collected 19 November 1998 respectively (Table 1 and 2). A surface soil sample (approx. top 2-in.) was also obtained on 13 August 1998 (Table 3; Figure 1 and 2).

Table 4 outlines irrigation and application dates, rates, and pH levels for the  $\text{H}_2\text{SO}_4$  study. The  $\text{H}_2\text{SO}_4$  was applied with each irrigation event in the irrigation stream (ditch) from a plastic tank at the head of the irrigation ditch, which was approximately 400 yards from the beginning of the  $\text{H}_2\text{SO}_4$  study area. The pH of the irrigation water was measured with a portable pH meter at each irrigation event both before and after the  $\text{H}_2\text{SO}_4$  was added to the irrigation  $\text{H}_2\text{O}$ . The pH of the irrigation water after addition of the  $\text{H}_2\text{SO}_4$  was measured at the beginning of the study area. Approximately three to five pH measurements were taken and the average of these measurements was recorded (approximately pH 7.6). The target pH of the irrigation  $\text{H}_2\text{O}$  for the  $\text{H}_2\text{SO}_4$  treatment was approximately 5.5. The basis for the rate of application of  $\text{H}_2\text{SO}_4$  was to lower the irrigation water pH to the target pH. Both treatments received every row irrigation throughout the growing season.

Each treatment received the same agronomic inputs with the only variation in management being the application of  $\text{H}_2\text{SO}_4$  to treatment 2 with each scheduled irrigation. Treatment 2 received approximately 108 gallons of water-run  $\text{H}_2\text{SO}_4$  during the course of the growing season (approx. 11 gal./acre/irrigation). Each treatment followed a feedback N management approach (UA guidelines; Silvertooth et al., 1990; Silvertooth et al., 1991b; Silvertooth et al., 1992; Silvertooth et al., 1993; Silvertooth et al., 1994; Silvertooth et al., 1995; Silvertooth and Norton, 1996; Silvertooth and Norton, 1997 and Silvertooth and Norton, 1998) where no N was applied after peak bloom (20 July) in this case.

Fertilizer applications were split with two side-dress applications of Ammonium Sulfate  $[(\text{NH}_4)_2\text{SO}_4 \text{ 21-0-0-24S}]$  and two water-run applications of UAN-32.

Routine plant measurements for each experimental plot were performed on a regular basis at approximately 14-day intervals throughout the season. Plant measurements taken included: plant height, number of mainstem nodes, number of flowers per 50 feet of row, percentage canopy closure, and the number of nodes above the top first position white flower (NAWF).

Soil water measurements for volumetric water content were also taken on a regular basis at approximately 14-day intervals for the first part of the growing season and on 30-day intervals throughout the rest of the season. Soil water measurements were made by use of a neutron moisture meter probe (CPN 503 DR hydroprobe, Campbell Scientific Nuclear, Martinez, CA) calibrated to the soil at the experimental site over a wide range of soil water contents. The measurements were taken immediately following an irrigation event. Soil water measurements were taken from all experimental units at one-foot intervals from the surface to a depth of five feet. The access tubes for the soil moisture measurements were placed in each plot approximately 200 feet above the tail of the field.

Surface soil samples were taken to a depth of approximately 2 inches on 13 August 1998. These surface soil samples were collected on the sides and in the seed row of the beds and analyzed for exchangeable Na percentage and  $\text{EC}_e$  (Figures 1 and 2).

The crop received the final irrigation on 8 September 1998. The entire study area was defoliated on 18 October 1998. Lint yields were obtained for each treatment on 19 November 1998 by harvesting the entire center four rows of each plot with a two-row mechanical picker. Lint turnout estimates were made (30%) by ginning the seedcotton obtained from the study area. Results were analyzed statistically in accordance to procedures outlined by Steel and Torrie (1980) and the SAS Institute (SAS, 1988).

## Results and Discussion

Plant growth and development patterns for both treatments are shown in Figure 3 (A, B, and C). The center line in all figures represents an optimal baseline for cotton in Arizona with the upper and lower lines representing the upper and lower 95% confidence interval thresholds (Silvertooth et al., 1996). Low height to node ratios (HNR) relative to baseline, indicating low plant vigor, were observed throughout the first portion of the growing season (Figure 3B). The HNR increased for both treatments throughout the rest of the growing season, particularly in relation to the dramatic drop in fruit retention (FR) in the early stages of the fruiting cycle. Treatment 2 had the greatest increase in HNR (vigor). The significantly greater HNR for treatment 2 was found on the last date of plant measurements on 8 September 1998 ( $P=0.0587$ ). Fruit retention levels dramatically decreased for both treatments from pinhead square (PHS) to peak bloom (PB) (Figure 3A). The large drop in FR contributed to the abrupt shift toward an increase in the HNR due to the plant becoming more vegetative in its growth. The higher NAWF values (Figure 3C) also indicate a more vegetative condition and delayed maturity associated with treatment 2 ( $\text{H}_2\text{SO}_4$ ).

The dramatic loss of fruit was due to the unusually high amounts of lygus that were present in the crop at the time of the drop in FR. A seed alfalfa field was adjacent to the east of the experimental area and was a constant source of lygus (primarily adults) infestation throughout the growing season.

Soil sample analyses revealed a reduction in Na from pre-season to post-season as indicated by a lowered ESP (Table 1 and 2). The  $\text{EC}_e$  levels also declined with the acid treatment showing the greatest reduction in  $\text{EC}_e$  and Na (ppm). Both treatments showed major decline in ESP from pre-season to post-season. There were no significant differences in  $\text{EC}_e$ , ESP, or Na (ppm) for the samples taken from six to ten inches between the treatments. The higher levels of  $\text{EC}_e$  and ESP in treatment 2 for the surface samples (Table 3) suggests that possibly more Na was released into soil solution and moved to the soil surface through evaporation than occurred in the control treatment (1).

Figures 4 - 7 present volumetric soil water data for four sample dates immediately following irrigation events in 1998. Analysis of variance performed on this data revealed significant differences among treatments with regard to soil water content at depths of one foot, 2, 3, and 5 feet on 2 July 1998 ( $P<0.05$ ). There were also significant

differences ( $P < 0.05$ ) at other dates of sampling during the growing season. The variability in the soil water data and the differences among replications indicate the inherent variability in soil physical properties in the study area. This observation is independent of treatment and is apparently due to natural soil conditions. This is why the study was arranged in a randomized complete block design with six replications and plots (experimental units) were 12 rows wide and extended the full length of the irrigation run.

Yields for both treatments are shown in Table 5. Yields were significantly higher for the no acid treatment than for the acid treatment ( $P = 0.0013$ ). This is due to the increased vigor that was evident in the acid treatment. The increased vigor of the acid treatment resulted in greater vegetative growth than did the check (zero acid) treatment. The increased vegetative growth was apparently due to increased water penetration in the acid treatment. It is also very important to recognize the importance of the lygus infestation that removed the fruit load on the lower fruiting branches of the plants. The loss of fruit on the bottom portions of the plant removed the primary sink for carbohydrates in the plant. The removal of the boll load and primary carbohydrate sink allowed for an increase in plant vigor, and thus, vegetative growth. The check (no  $H_2SO_4$  treatment) was also damaged by the lygus infestation, however its vigor did not increase in the same proportions as the  $H_2SO_4$  treatment. Irrigation intervals were maintained to prevent stress in the check (no  $H_2SO_4$ ) plots. Therefore, plots receiving  $H_2SO_4$  were possibly irrigated too frequently, particularly with low FR and high vigor (HNR). At harvest, the  $H_2SO_4$  treatment had a significant amount of unopened bolls at the upper portions of the plant indicative of a late crop. The check (no  $H_2SO_4$  treatment) did not have a large portion of unopened bolls in the upper portions of the plant, hence, it produced an earlier crop.

These results demonstrate the sensitive balance between vegetative and reproductive growth in a cotton crop. The most critical growth stimulants in the soil-plant system are water and N. Both water and N contribute to the support of a boll load and the yield potential. However, under conditions of a low fruit load (FR) and / or high vigor (HNR), the management of water and N become increasingly critical. In the case of  $H_2SO_4$  use, water penetration and availability can obviously be enhanced. Therefore, these results reinforce the importance of complete and efficient management of all crop inputs in relation to actual crop conditions, that requires careful monitoring in the field.

### **Acknowledgment**

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Table 1. Pre-season bulk soil sample taken from field 1, borders 39–50 at MAC 22 April 1998.

Sample #	Depth	pH (1:1 H <sub>2</sub> O)	Ca* (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	EC <sub>e</sub> (dS/M)	NO <sub>3</sub> <sup>-</sup> -N** (ppm)	P*** (ppm)	ESP§	Free Lime
Bulk	6" – 10"	8.1	5200	410	720	370	11.0	48.5	12	9.3	High

\* Exchangeable cations using neutral molar ammonium acetate.

\*\* NO<sub>3</sub><sup>-</sup>-N using ion specific electrode.

\*\*\* NaHCO<sub>3</sub> extractable P.

§ Computed - exchangeable sodium percentage.

Table 2. Post-season soil samples taken from field 1, borders 39-50 at MAC 19 November 1998.

Sample #	Depth	pH (1:1 H <sub>2</sub> O)	Ca* (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	EC <sub>e</sub> (dS/M)	NO <sub>3</sub> <sup>-</sup> -N** (ppm)	P*** (ppm)	ESP§	Free Lime
Acid	6" – 10"	8.2	4900	300	310	310	4.0	14.0	13.0	4.6	High
No Acid	6" – 10"	8.1	5500	330	350	330	4.8	11.8	12.0	4.7	High

\* Exchangeable cations using neutral molar ammonium acetate.

\*\* NO<sub>3</sub><sup>-</sup>-N using ion specific electrode.

\*\*\* NaHCO<sub>3</sub> extractable P.

§ Computed - exchangeable sodium percentage.

Table 3. Surface soil samples taken from the wet side (WS) and seed row (SR) from in field 1 MAC 13 August 1998.

Sample #	Depth	pH (1:1 H <sub>2</sub> O)	Ca* (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	EC <sub>e</sub> (dS/M)	NO <sub>3</sub> <sup>-</sup> -N** (ppm)	P*** (ppm)	ESP§	Free Lime
Acid WS	5 cm	7.8	5000	280	320	190	5.8	88.9	16.0	4.8	High
Acid SR	5 cm	7.7	5200	310	900	300	17.5	164.1	21.0	11.8	High
No Acid WS	5 cm	8.0	4900	270	240	210	5.0	40.7	14.0	3.7	High
No Acid SR	5 cm	7.8	5000	300	720	310	12.5	98.8	18.0	10.0	High

\* Exchangeable cations using neutral molar ammonium acetate.

\*\* NO<sub>3</sub><sup>-</sup>-N using ion specific electrode.

\*\*\* NaHCO<sub>3</sub> extractable P.

§ Computed - exchangeable sodium percentage.

Table 4. Treatment application dates and rates, acid study, MAC, 1998.

Irrigation Date	Treatment		Treatment	
	1	2	1	2
	lbs. N/acre		gal. H <sub>2</sub> SO <sub>4</sub> /acre	
8 May	0	0	0	7
14 May	0	0	0	11
11 June*	40	40	0	0
17 June	0	0	0	12
1 July**	35	35	0	12
14 July**	35	35	0	12
20 July*	40	40	0	0
22 July	0	0	0	11
4 August	0	0	0	9
13 August	0	0	0	12
25 August	0	0	0	11
8 September	0	0	0	11
<b>Total</b>	<b>150</b>	<b>150</b>	<b>0</b>	<b>108</b>

\* Side dress fertilizer application of Ammonium Sulfate ((NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>).

\*\* Water run fertilizer application of UAN-32.

Table 5. Lint yields for each treatment, acid study, MAC, 1998.

Treatment	lbs. Lint/acre	bales/acre
No Acid	822.68a	1.71
Acid	686.97b	1.43
LSD*	55.02	
OSL†	0.0013	
C.V.(%)‡	3.56	

\* Least Significant difference

† Observed Significance Level

‡ Coefficient of Variation

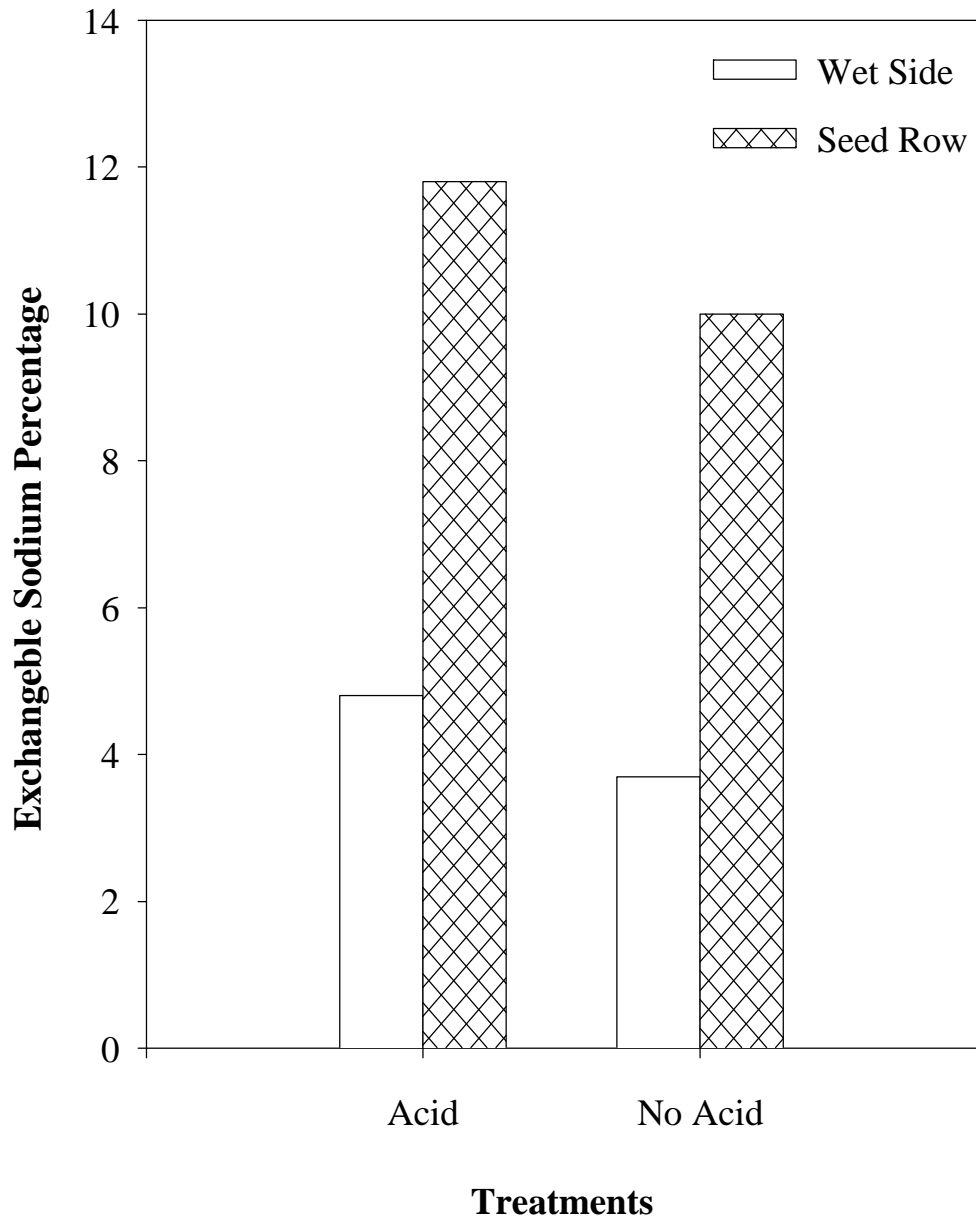


Figure 1. Exchangeable sodium percentage for each treatment across the seed bed, acid treatment, MAC, 13 August 1998.

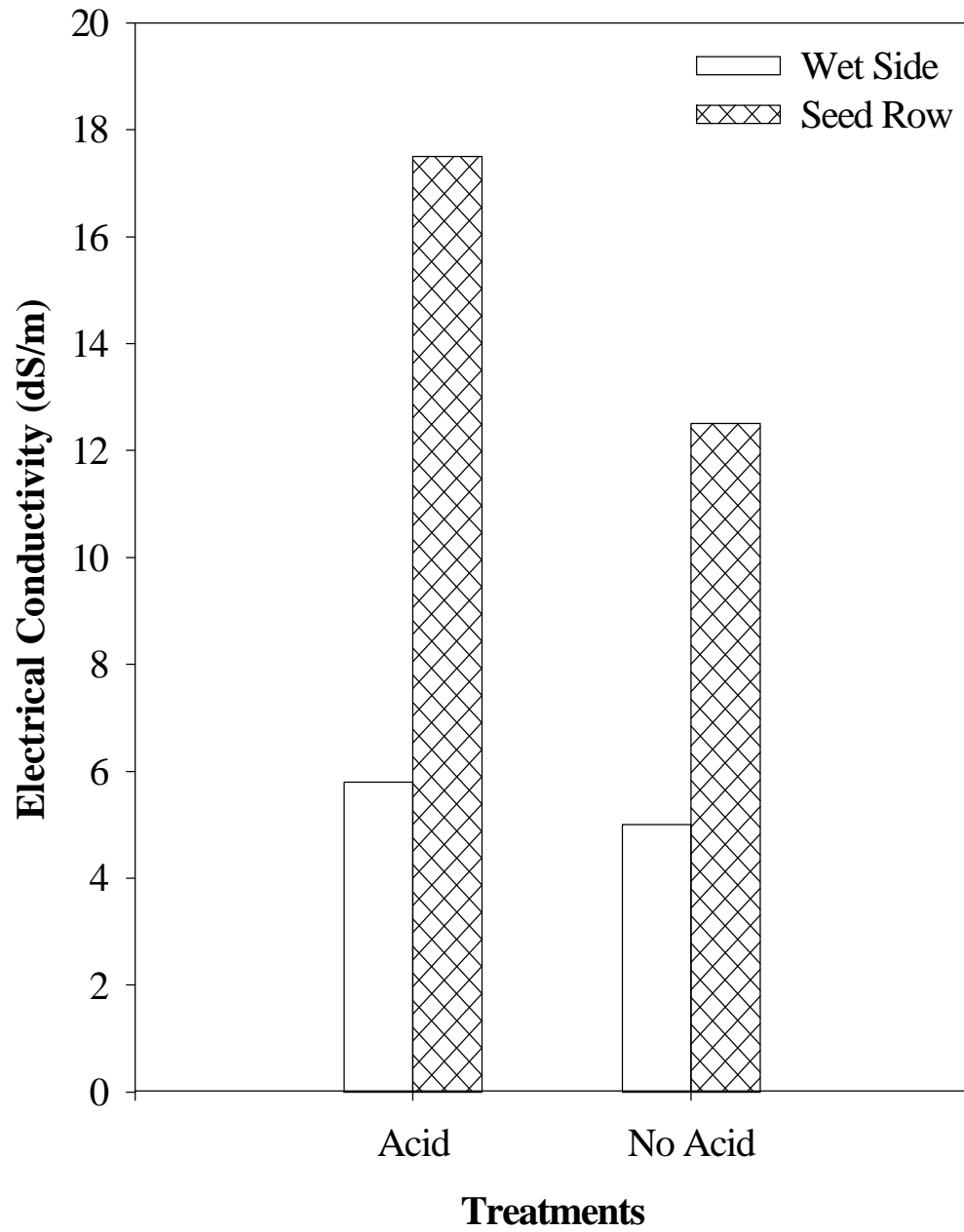


Figure 2. Electrical conductivity results for each treatment across the seed bed, acid treatment, MAC, 13 August 1998.

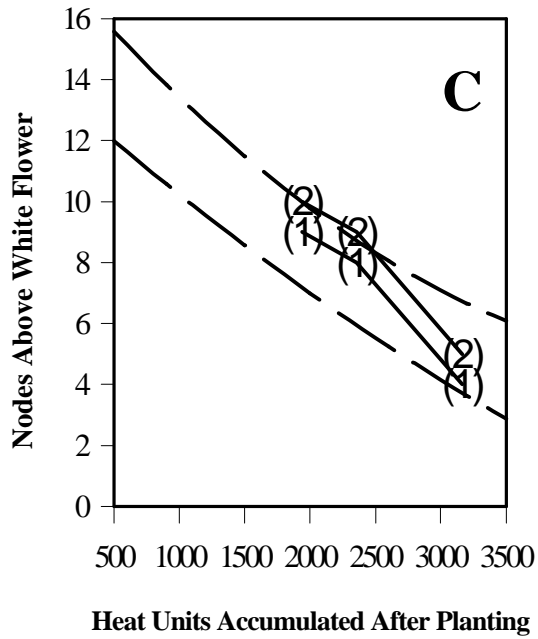
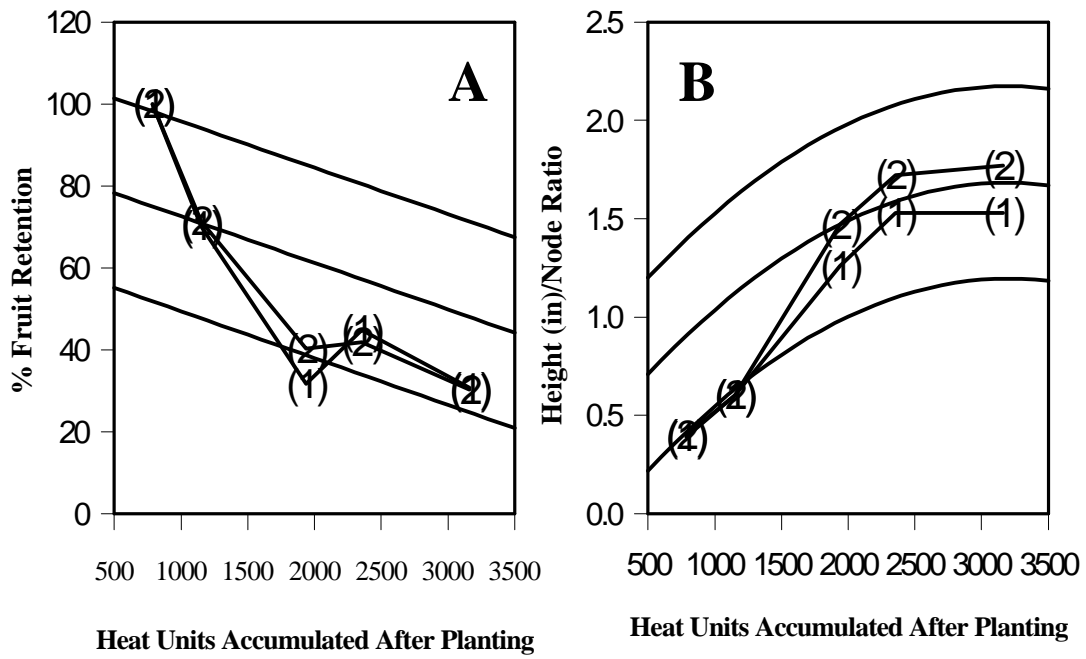


Figure 3. Data summaries for ; A) fruit retention B) height to node ratios, and C) nodes above white flower.

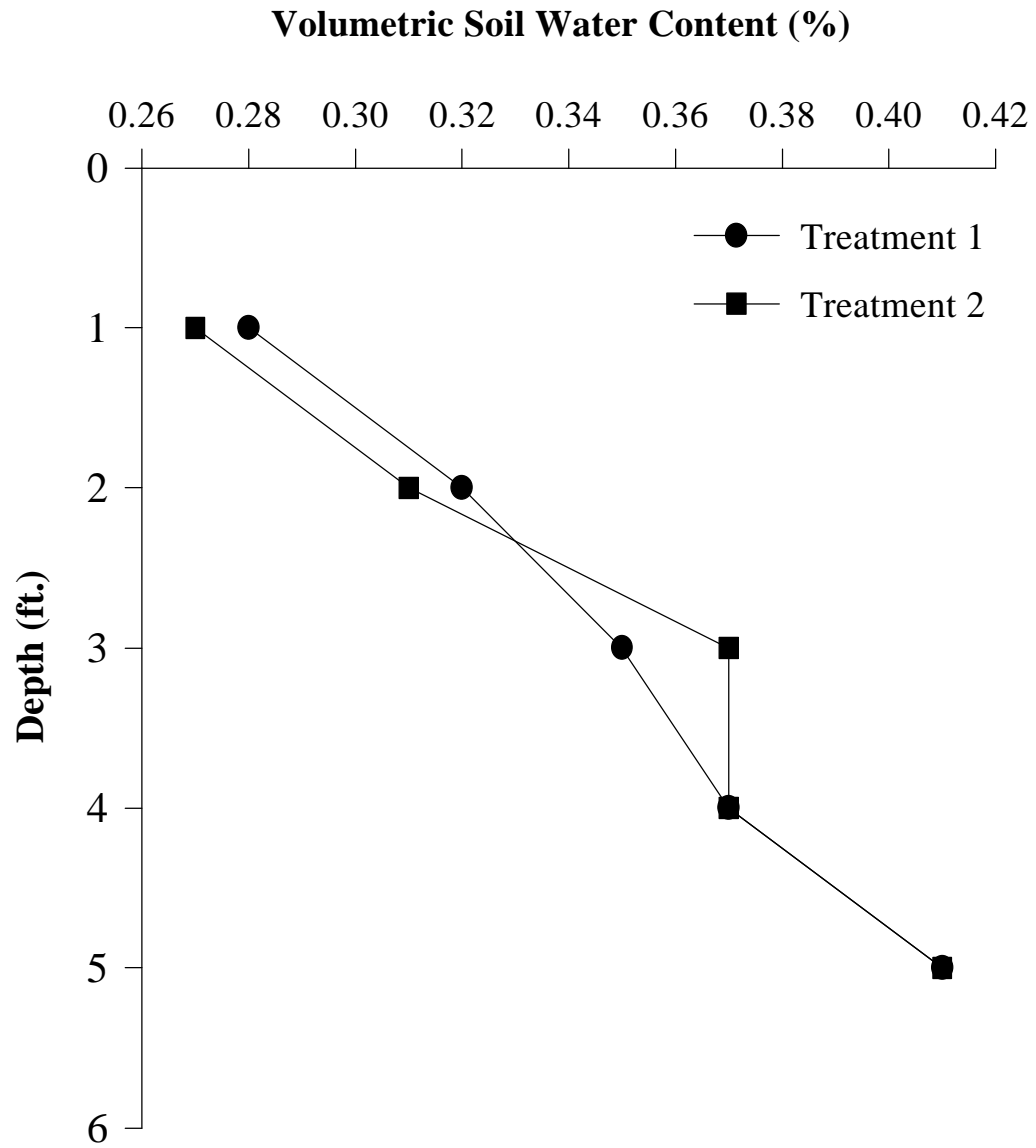


Figure 4. Volumetric soil water content (%) results for each treatment, acid treatment, MAC, 16 June 1998.

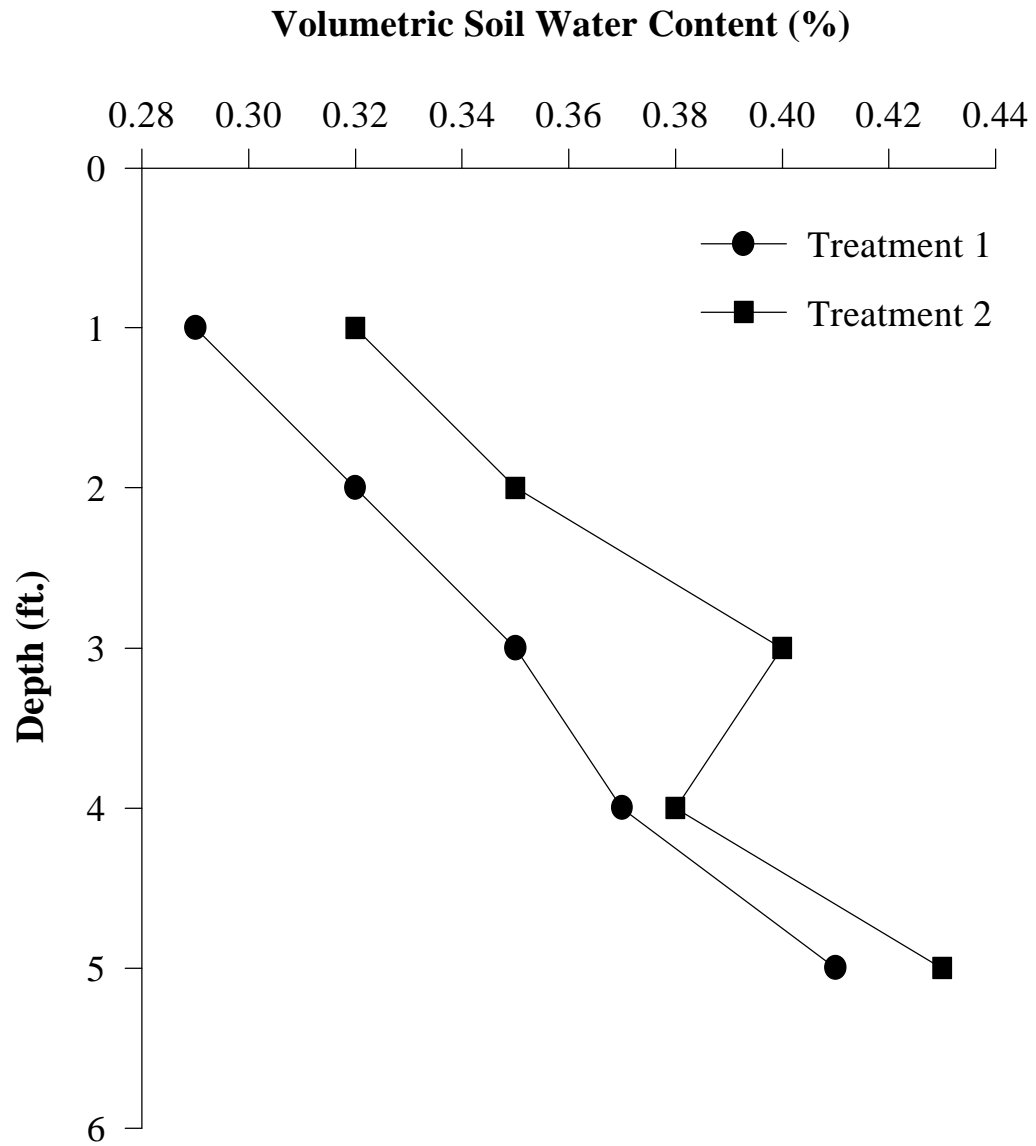


Figure 5. Volumetric soil water content (%) results for each treatment, acid treatment, MAC, 2 July 1998.

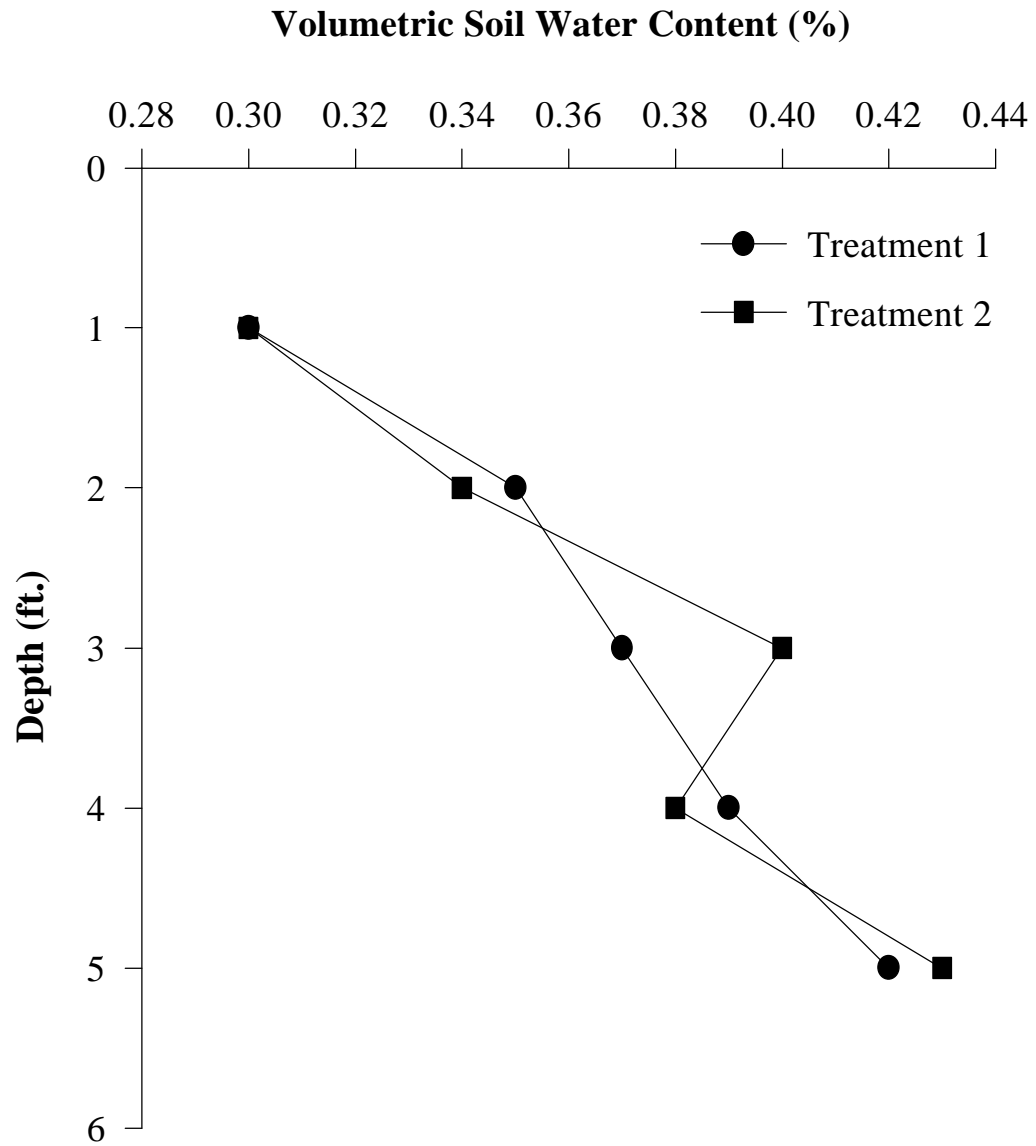


Figure 6. Volumetric soil water content (%) results from each treatment, acid treatment, MAC, 15 July 1998.

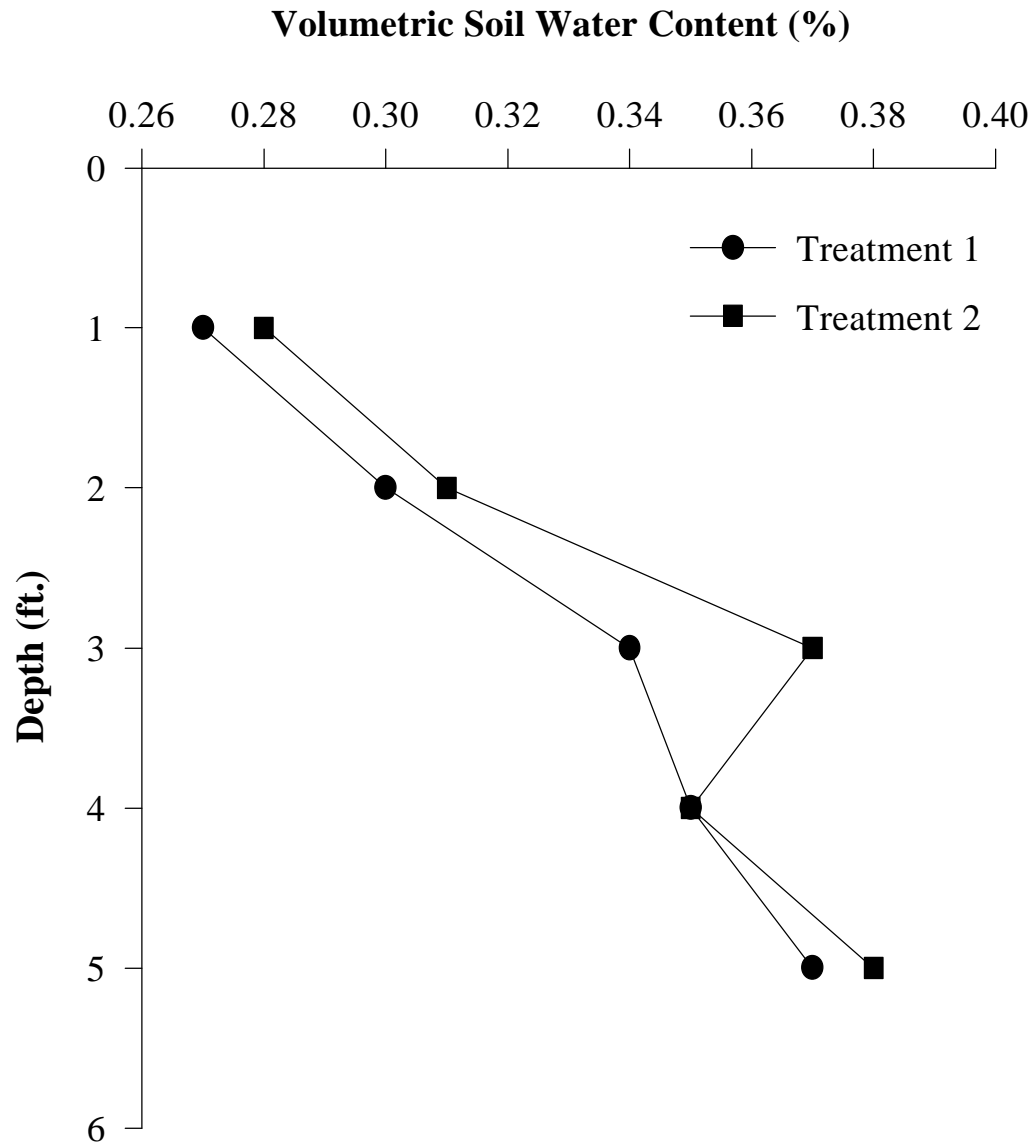


Figure 7. Volumetric soil water contents (%) results from each treatment, acid treatment, MAC, 14 August 1998.