ACIDIFICATION OF ALKALINE IRRIGATION WATER: EFFECTS ON NUTRIENT AVAILABILITY, YIELD AND QUALITY OF SWEETCORN ON ALKALINE SOILS

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ABSTRACT

More than 9,000 acres of sweet corn are grown each year in western Colorado with a farm-gate value of approximately $16 million. Over the past decade growers and extension agents have noticed a steady increase in soil pH along with an increase in micronutrient deficiencies. Preliminary soil tests on this calcareous soil showed pH ranging from 7.5 to 8.0. Irrigation water pH is high and increases through the season. In early June irrigation water pH is near 7.8 and increases to 8.3 in the latter part of the growing season. Water analysis showed bicarbonate levels in the irrigation water range from 650 ppm to 900 ppm. This study was initiated to determine if acidifying the irrigation water and/or amending the soil with compost or elemental sulfur could reduce soil pH and improve the soil nutrient availability and improve crop yield and quality. This was an on-farm study using standard commercial sweet corn practices. The design was a split plot with acidification/no acidification as the main plot treatments and compost (10 tons ac^{-1}), elemental sulfur (1/2 ton ac^{-1}) and a control as the sub-plot treatments, for a total of six treatments. The first year's results, 2004, did not show any significant differences in any soil or crop parameter tested. However, in year two there were significant differences in soil pH with the lowest pH in the acidification-compost treatment, and phosphorus and potassium were significantly higher in the both compost treatments. The highest number of marketable ears were in the three acidified irrigation water treatments versus the no acid control. Brix was significantly higher in both compost treatments than the no acid-control. Following the second year of this three-year study we can conclude that irrigation water acidification and compost additions are improving a number of soil and crop parameters.

INTRODUCTION

Sweet corn grown in the Uncompahgre Valley of western Colorado is a high value crop with more than 9,000 acres of sweet corn grown annually with a farm-gate value of approximately $16 million (CASS, 2004). The calcareous soils in the Uncompahgre Valley have been under irrigated agriculture for more than one hundred years. Growers in the area have been noticing a decline in soil quality and productivity over the last 10 to15 years. This decline is probably due in part to rising soil pH levels that reduce crop nutrient availability that leads to reduced crop health, vigor and yield. Preliminary investigations showed the irrigation water and soil have high pH levels. Initial measurements of irrigation water pH ranged from pH = 7.8 to 8.3 and soil pH from 7.5 to 8.0. High levels of bicarbonate in the irrigation water are probably responsible for exacerbating the situation with levels between 650 – 900 ppm. This study was initiated to determine if acidifying the irrigation water and/or amending the soil with acidifying soil amendments could reduce soil pH and improve the soil and crop quality. Typically, soils in the Uncompahgre Valley contain from 1.5 to 5% lime and are therefore highly buffered (Swift, 2005). Many researchers have studied the use of sulfuric acid added directly to the soil to reduce soil pH in calcareous soils and as an aid to reclamation of sodic and alkaline soils (Miyamoto, et al., 1974; Miyamoto, et al., 1975c; O'Connor and Lee, 1978; and Stroehlein and Pennington, 1986) or used compost for the same purpose (Avnimelech, et al., 1994). However, the lack of application equipment cost of direct soil application of sulfuric acid and high irrigation water bicarbonate levels necessitated application in the irrigation water. Some researchers have studied the effects of sulfuric acid additions to irrigation water on soil properties and nutrient availability (Miyamoto, 1977; and Mohammed, et al., 1979). However, few researchers have studied the effects of irrigation water acidification and compost addition alone or in combination on vegetable yields on calcareous soils. This three-year study was begun in 2004 in cooperation with John Harold, a sweet corn grower in Olathe, Colorado to determine the effects of irrigation water acidification alone and in combination with compost or S on crop yield and quality and crop nutrient availability. This study used six treatments, acidification or no acidification of the irrigation water coupled with compost, sulfur or no soil amendment (control). The first year's results showed no significant differences in any soil or crop parameters tested, there were trends towards lower soil pH and increased nutrient availability in the treatments that had either the irrigation water acidified or compost added or both. In 2005, however, there were significant differences in many soil and crop parameters indicating that treatments are beginning to have some effect on these highly buffered soils.

MATERIALS AND METHODS

This on-farm research was conducted in cooperation with John Harold in Olathe, Colorado in the Uncompahgre Valley in 2004 and 2005. Sweet corn (*Zea mays* L.) var. Chief Ouray (Mesa Maize, Olathe, Colorado) an 85 day relative maturity super-sweet corn was planted in the first week of June and harvested either the last week of August or the first week of September, 2004 and 2005 respectively. Plant populations were 26 400 ac^{-1} (8 inches between plants). All plots were side-dressed at the six-leaf stage with 150 lbs N ac^{-1} using liquid 28-0-0. The corn was furrow irrigated approximately every week as needed throughout the season. Irrigation sets were 12 hours long. There were 13 irrigations in 2004 and 14 irrigations in 2005. Reference ET for 2004 was 24.1 inches and 23.3 inches for 2005, determined at a Colorado State University meteorological station approximately 3 miles from the study field. The soil is a Cherylade clay loam [fine-loamy, mixed, mesic, Typic Haplargid]. The experimental design is a split plot design with two main plot factors, acidification or no acidification of irrigation water, and three sub-plot factors, soil amendments of composted chicken manure (10 tons ac^{-1}), elemental sulfur (S) (1/2 ton ac^{-1}), or no amendment (control), for a total of six treatments and three replications. The 18 plots are 16 rows wide (30 inches on center) by 1100 feet long for a total of one acre per plot. Treatments were: 1) no irrigation water acidification and compost added (NAC), 2) no acidification and S added (NAS), 3) no acid control (no soil treatment imposed as a check, this is also standard farmer practice) (NACon), 4) irrigation water acidification and compost added (AC), 5) acidification and S added (AS) and 6) acidification only (ACon).

Irrigation water samples were taken throughout the season at each irrigation and monitored for pH. Irrigation water acidification was done using commercially available concentrated sulfuric acid, approximately 17.5 molar concentration, dripped into the irrigation ditch to reduce irrigation water pH to approximately pH = 6.5. Sulfuric acid use was approximately 40 gals ac^{-1} for the season at a cost of $2 per gallon.

Twenty soil cores were taken randomly from the surface foot from each plot and composited, air dried and sent to a commercial soil testing lab for complete analysis. Soil samples were taken from each of the 18 plots prior to planting, at mid-season and following harvest each year. Yields were determined by counting the number of 48 ear boxes (standard commercial container) harvested per plot. Harvesting was done using commercial sweet corn harvesting crews and equipment. Two sweet corn parameters were used to define quality, the average ear weight and brix, or percent soluble solids, a standard measure of sweetness in the fruit industry. Although ear weight and brix are not criteria for grading provided the ear is of marketable size and sufficiently developed, they are critical marketing criteria. A standard hand-held refractometer was used to measure brix (McCormick Fruit Tech, Yakima, WA). At harvest, 10 ears were taken at random from each plot to determine an average ear weight and average brix. To determine brix, kernels were cut from the 10 ears, mixed thoroughly and the juice pressed onto the refractometer lens using a hand garlic press. The reading was repeated three times and the readings were averaged for each plot. All crop and soil data was analyzed statistically at a least significant difference of 0.1 or 90% certainty level (SAS, 1985). There was no water treatment by soil amendment interactions, therefore all treatments were analyzed together.

Following harvest the residue was grazed by cattle for approximately 2 weeks and then the stubble was disced into the soil the following spring as part of the next season's field preparations.

RESULTS AND DISCUSSION

Irrigation Water

Irrigation water pH taken at the field at each of the irrigations throughout the growing season ranged from 7.8 to 8.3, from planting to harvest, respectively, and averaged pH = 8.1. The principle reason for the high pH in the irrigation water is due to dissolved bicarbonates in the water. Bicarbonate levels ranged from 650 – 900 ppm through the growing season.

The amount of sulfuric acid needed to neutralize the high irrigation water pH (to pH = 6.5) averaged 18 gallons per acre-foot of irrigation water. The estimated water application for both years was approximately 2.25 acre-feet ac^{-1}.

Sweet Corn Yield, Quality and Revenue

The sweet corn yields were higher in the three treatments receiving acidified irrigation water than the non-acidified treatments, however, the yields were only significantly higher than the NACon treatment (Table 1). It appears that the sweet corn yields are responding to treatments, with the most response due to acidification of the irrigation water as opposed to soil treatments alone. There has been little work done on the effects of high soil pH on corn productivity or the maximum soil pH tolerated by corn before exhibiting yield declines. However, it appears that although the soil pH in the top foot of soil has not been significantly reduced in all acid treatments (data presented below), the reduced pH of the irrigation water is having a positive effect on sweet corn yields by possibly temporarily reducing the pH in the root zone.

Sweet corn ear weights were significantly higher in the NAC treatment than the NACon and the AS treatments with other treatments falling in-between (Table 1). There is no discerable pattern or trend and the reason for these results is not apparent at this time. The sweet corn brix was significantly higher in both compost treatments than the NACon treatment (Table 1). The K in plants aids in sugar translocation from the leaves to the fruit; the higher the plant K the more sugars are translocated (Marschner,1995). Higher soil K in the compost treatments may be directly responsible for higher brix in the sweet corn in those treatments.

The wholesale price for sweet corn in 2004 and 2005 averaged approximately \$8 box^{-1} (John Harold, personal communication). Calculations for the increases in production cost of acidifying the irrigation water were approximately \$80 ac^{-1} using a cost of \$2 gal^{-1} for sulfuric acid. The revenue generated by the increase in corn yield for non-control treatments over the NACon treatment, the control or farmer standard practice, is given in Table 1. This calculation does not take into account the added time/labor costs of irrigation water acidification that averaged an additional half hour of labor per irrigation or the additional input costs of the S or compost. These calculations show that the acidification of irrigation water in combination with or without soil amendments increased grower revenue from between \$144 and \$296 (Table 1). This suggests that the farmer standard practice may be detrimental to the soil and the farmer.

Table 1. Sweet corn yield, ear weight, brix, income and net revenue.

Treatment	**Yield** (boxes ac^{-1})	**Ear Weight** (g)	**Brix** (% sol. solids)	**Income** (@\$8 box^{-1})	**Cost of Acid** (@ \$2 gal^{-1})	**Net Revenue** (\$ gain over NACon)
NAC	460ab†	294a†	20a†	\$3680	\$0	\$104‡
NAS	457ab	288ab	19ab	\$3656	\$0	\$80
NACon	447b	272c	17b	\$3581	\$0	\$0
AC	475a	280abc	20a	\$3803	\$80	\$144
AS	476a	270c	19ab	\$3805	\$80	\$152
ACon	494a	274bc	19ab	\$3949	\$80	\$296

† letter followed by different letter significantly different at $P < 0.1$.
‡ Net revenue = (treatment income – (NACon income + cost of acid).

Soil Quality

The soil quality parameters that were examined for this study include soil pH, EC, soil organic matter (SOM), and essential crop nutrients. Significant differences were observed in some of the soil parameters examined in 2005, showing that the treatments were starting to have an effect on soil quality in the second year of the study. These results also show that the soil system is well buffered.

The soil pH prior to the start of the study in 2004 averaged pH = 7.9. As of the fall of 2005 soil pH had dropped significantly in AC treatment compared to NAS and NACon (Table 2). The slight drop in pH in the NAS and NACon is probably due to field variabitliy (Table 2). It appears the AC treatment is having the most effect on soil pH probably due the combination of acidification and compost additions, as expected. The sulfur does not appear to be having the desired effect on soil pH. The pH in the NAS treatment is the same as the NACon and the pH in the AS treatment is the same as the ACon. The reason for this is not know at this time.

Soil salinity (EC) did not show any significant difference between treatments; however, the average salinity was higher in fall 2005, at 1.0 mmhos, than in spring 2004, at 0.5 mmhos. This increases is probably due to soil deposition of salts contained in the irrigation water. It was expected the acidified treatments would have significantly higher salinity levels because of the reaction of soil lime with the acidified irrigation water. However, calcium has the beneficial effect of “opening up” clayey soils, making the soil more porous. This in turn may have allowed more water infiltration and movement of salts below the one foot sampling zone.

Although the compost treatments had slightly higher SOM there were no significant differences in SOM levels for 2005 and averaged 1.23%. The SOM level prior to the start of the study was 1.18%.

There were no significant differences in soil nitrate-nitrogen (NO_3-N) following this year's harvest and residual soil NO_3-N averaged 50 ppm. Available soil phosphorus (P) did show significant differences for 2005 with the compost treatments having significantly higher soil P than any other treatments (Table 2). These higher levels are due to the additions of P from the compost. Approximately 250 lbs P ac^{-1} was added from the compost in 2005. Soil potassium (K) levels were significantly higher in the compost plots than in any of the other treatments, this is also due to the potassium contained in the compost (Table 2). Approximately 350 lbs K ac^{-1} was added from the compost in 2005. Soil zinc (Zn) was also significantly higher in the treatments receiving compost than the AS and ACon treatments (Table 2). The lower Zn levels in these treatments may be due to higher yielding treatments having more zinc uptake than the lower yielding treatments. Soil manganese, copper, sulfur, iron and boron did not show any significant differences between treatments. It is possible that these parameters will begin to show some differences following next year's work.

Table 2. Sweet corn soil parameters.

Treatment	**Soil pH**	**P** (ppm)	**K** (ppm)	**Zn** (ppm)
NAC	7.70ab†	97a†	372a†	8.5a†
NAS	7.85a	41c	248b	7.4bc
NACon	7.85a	38c	243b	7.4bc
AC	7.62b	84b	327a	8.1ab
AS	7.70ab	40c	228b	6.9c
ACon	7.70ab	39c	234b	6.9c

† letter followed by different letter significantly different at $P < 0.1$.

CONCLUSIONS

The soil pH was lower where acid and compost treatments were imposed. Soil phosphorus (P) and potassium (K) levels are significantly higher in compost amended treatments as would be expected. Marketable yields were highest where acid was added to the irrigation water. Brix measurements were highest where compost was added. In general, second year results showed improvements in soil quality and corn yield and quality where irrigation water acidification and compost treatments were applied.

These results show significant differences in many of the crop and soil parameters tested. The results indicate that the soil and crop are responding to treatments following a second year of treatment applications. It appears from these results that the compost is enriching the soil more than other treatments, and that the acidification is enhancing the benefits of all inputs and improving the soil quality in general.

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