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CONDITIONING SALINE COTTON FIELDS TO ENHANCE MINIMUM TILLAGE PRACTICES

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Abstract

Reclaimed effluents and salty ground waters are used on cotton fields in West Texas because it is a necessity. Concentrations of total salinity and sodium of typical wastewaters often double compared with potable water, which may double again with the use of shallow groundwater. We hypothesize that conditioning soils with biosolids (wastewater treatment plant residuals) may extend the upper limit of allowable salinity and sodicity of irrigation water and possibly minimize mechanical cultivation for transgenic cotton culture. This study investigated the impacts of co-utilization of biosolids and marginal water on soil chemical conditions, in particular surface salt accumulation in continuous and minimum tillage systems. Multiple applications of anaerobically-digested biosolids was applied onto two large commercial fields for a total loading rate of 18.6 dry tons A^{-1}. Treatments included two tillage systems, four soil mapping units, and four positions on 30-in beds. Soil and irrigation water pH, electrical conductance (EC), soluble calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^{+}) were evaluated in 2001 and 2002. Ammonium nitrogen was also monitored as an indicator of organic matter decomposition and as a source of charge contributing to soil EC. Field results suggest that minimum tillage increased soil salinity and sodicity. Surface salt accumulation was greater in clayey textured than loamy-textured soil. Salts initially accumulated on the top of the cotton beds, but eventually became more uniformly distributed across the bed with time. Minimum tillage improved lint yields on a loam soil, but reduced lint yields on clayey soils. Biosolids alone did not condition soils to receive degraded irrigation water. Biosolids in combination with mechanical cultivation prevented surface soil salinity and sodicity.

Introduction

Reclaimed wastewater and/or salty ground waters are often used on cotton fields in West Texas because it is a necessity. Concentrations of total salinity and sodium of typical wastewaters often double compared with potable water, which may double again with the use of shallow groundwater. The sodium adsorption ratio (SAR) of typical wastewater increases to 5 to 8, which may become detrimental to the structural stability of many irrigated soils. Soil tilth and productivity are often severely damaged (Sadan and Felesh, 1998). Salts may accumulate in soils at the surface with insufficient leaching or can contaminate ground waters with excess leaching. The salinity of irrigation water sources is expected to increase as potable supplies are reallocated to growing border populations in West Texas. Saline irrigation water may reach concentrations greater than one third the strength of sea water (> 10,000 ppm). Current water issues and cotton production in West Texas reflect forthcoming water issues in other irrigated regions.

Organic matter management using biosolids may provide a novel strategy in conditioning soils to prevent or remediate salt and sodium hazards. Historically, the nutrient value of biosolids to plants has overshadowed a detailed evaluation of biosolids to condition or change the physiochemical characteristics of soil (Tester, 1990). However, increased soil salinity (measured as electrical conductivity, EC) has been noted following biosolids application (Epstein et al., 1976). Fine et al. (1984) and Fine and Mingelgrin (1996) found that mineral N species, mainly as nitrate contributed to salinity. These and similar observations led Levy et al. (1986) to suggest that NH_4^{+}, a product of biosolids degradation and Ca^{2+}, that is solubilized following nitrification and respiration-induced acidification, may displace sodium on the exchange complex to reduce the exchangeable sodium percentage (ESP).

Assadian and Fenn (1995) also observed salinization immediately following biosolids incorporation in field trials, but also found a reduction in soil salinity and sodicity after one growing season. Alleviation of cotton moisture stress indirectly suggested that biosolids incorporation increased rather than decreased the available water supply in the soil profile. Salts, particularly Na^+, were readily leached from biosolids amended soil in a companion soil column study.

Prevention of salt accumulation appears to be associated with physical changes in soil. Biosolids conditioning has significantly reduced soil bulk density (Lindsay and Logan, 1998; Tester, 1990; and Wong and Ho, 1991), and increased gravimetric moisture content and soil moisture retention (Lindsay and Logan, 1998; Metzger and Yaron, 1987). Soil permeability was been enhanced (Wei et al., 1985) and penetration resistance reduced (Tester, 1990). Biosolids have improved soil aggregation (Glauser et al., 1988), which Pagiliai et al. (1981) associated with increases in total soil porosity. Physical changes have persisted over time (Pagiliai et al., 1981; Wei et al., 1985; and Lindsay and Logan, 1998) and have often improved saturated hydraulic conductivity (Wei et al., 1985; and Wong and Ho, 1991). Still, Agassi et al. (1998) found that soil infiltration decreased following biosolids application. They attributed that to particulate and microbial clogging of soil pores.

Growers rely on cultivation and plant rotation to physically break salt crusts and/or hardpans, and fluff soil to improve water infiltration. For example, cotton fields in far West Texas are mechanically cultivated at least once each irrigation cycle, in addition to extensive pre-plant soil preparation. Soil operations approximately cost \$66 ha^{-1} or 47% of pre-harvest operation costs (Libbin et al., 1993). Replacement of mechanical cultivation, even in part, with biosolids conditioning in a minimum or no-till system would directly translate into time, money, and energy savings. This is in addition to the fertilizer value of the biosolids.

This project represents an initiative to develop regional sustainability in areas of limited water supplies. The co-utilization of reclaimed effluents and/or marginal-saline water (Bouwer 1992; and Haruvy, 1997) and biosolids (Outwater, 1994) for agriculture may provide municipalities the better use of limited water supplies and land resources. The use of alternative materials for purchased inputs and the development of low-energy management strategies will dramatically decrease farm operations and increase profitability.

We hypothesize that conditioning soils with biosolids may extend the upper limit of allowable sodicity of irrigation water and possibly minimize mechanical cultivation for transgenic cotton culture. This study investigated the impacts of co-utilization of biosolids and marginal water on soil chemical conditions, and surface salt accumulation in a minimum tillage system.

Materials and Methods

The test site was located at Ft. Hancock at Hudspeth County, TX at the southern end of the upper Rio Grande floodplain and within the Chihuahua Desert. The region is arid and rainfall typically averages 8 to 10 inches annually with a growing season of 248 days. Mean annual temperatures are 58 to 68 ^oF. Cotton culture is completely dependent on irrigation, but growers in Hudspeth County do not have surface water rights and are oftentimes dependent on treated effluents or irrigation return flow for irrigation. Water quality is often degraded (>2,000 mg L^{-1} total dissolved solids), but still preferable to the use of highly saline ground waters. Floodplain soils (Typic Torrifluvents) are heterogeneous and moderate alkaline. Soil textures include loams to silty clays that are susceptible to salt hazard.

Two commercial fields (> 60 A) were amended with multiple applications of anaerobically-digested biosolids from the Roberto R. Bustamante Wastewater Treatment Plant in El Paso, TX, and surface applied at loading rates of 4.8, 6.5, and 7.3 dry tons A^{-1} in 1999, 2000, and 2001 for a total of 18.6 dry tons A^{-1}. In 2001 and 2002, Roundup Ready™ transgenic was planted to 30-in beds. One field received continuous tillage, and the second field received minimum tillage. Minimum tillage included soil disking and bed formation prior to planting and bed reshaping after the first post-plant irrigation. Continuous tillage included pre- and post- plant soil operation in addition to regular cultivation after every furrow irrigation. Within each field, four dominant soil mapping units were identified and included Glendale silty clay loam (Ge), Glendale silty clay (Gs), Harkey loam (Ha), and Tigua silty clay (Tg). Surface soil samples to a depth of 3 inches were collected from the top, sides, center and furrow of selected cotton beds within each soil mapping unit. Soil was collected in duplicate after every irrigation when soil was dry enough for field entry. Irrigation water samples were also collected over a 2-yr period. The treatment design was a 2x4x4 factorial for tillage system, soil mapping unit, and bed position. The experimental design was an incomplete randomized block with 2 replications and 8 repeated observations over a 2-yr period.

All soil samples were air-dried and sieved through a 2-mm sieve. A 1:1 soil to deionized water extract was prepared for each sample to determine electrical conductance (EC) and pH, and the soluble concentrations of sodium (Na^{+}), calcium (Ca^{2+}), and magnesium (Mg^{2+}) using atomic absorption spectroscopy (EPA200.1). The sodium adsorption ratio (SAR) was calculated following the equation in Handbook 60 (1954) and was used as a chemical index to describe the structural stability of soil in different sections of the single-row bed. Ammonium nitrogen (NH_4^{+}-N) was determined by soil extraction with 2 M KCl, steam distillation protocols with dried MgO, and back titration using sulfuric acid following (Mulvaney, 1996). Irrigation water samples were filtered and analyzed in an identical manner to soil extracts.

The impacts of tillage system, soil mapping unit and bed position on soil surface salinity and sodicity in 2001 and 2002, and lint yields in 2001 were statistically delineated using ANOVA. Least significant differences at the 0.05 level of probability delineated treatment effects.

Results and Discussion

Sources of salinity were irrigation water, biosolids, and/or field soils (Table 1). The dominant source of salinity was irrigation water, despite the fact that biosolids EC was $\geq$ 3.0 dS m^{-1}. A total biosolids loading rate of 18.6 dry tons A^{-1} introduced approximately 74 lbs of total dissolved solids (salts). Conversely, irrigation water with an EC between 1.2 and 2.6 dS m^{-1} introduced 2.6 to 5.7 tons of salt yr^{-1}, given that about 2.5 acre-ft of irrigation water were applied to cotton each growing season. Soil EC was < 4 dS m^{-1} and SAR < 13, indicative of a nonsaline or nonsodic soil prior to the application of biosolids or minimum tillage. However, moderate soil salinity combined with an average SAR of 7.9 also indicated that field soils were susceptible to sodic hazard. Irrigation water introduced relatively high Na^{+} concentrations relative to those of Ca^{2+}.

Table 1. Quality of irrigation and anaerobically-digested biosolids applied to soils at Ft. Hancock, TX.

Chemical Quality	Irrigation Water[1]	Biosolids[2]	Soil[3]
EC[4], dS m^{-1}	1.21 - 2.64	3.0 - 3.1	1.3 - 1.7
Ca, mg kg^{-1}	38 - 97	386 - 401	60 - 115
Mg, mg kg^{-1}	18 - 26	715 - 841	10 - 23
Na, mg kg^{-1}	184 - 539	1181 - 1326	287 - 311
SAR[5], ratio	4.5 - 8.1	--	6.6 - 9.6
NH_4-N, g kg^{-1}	--[6]	6.5 - 11.7	--

[1]Based on 8 samples collected in 2001-2002.
[2]Based on triplicate samples collected annually from 1999-2001.
[3]Based on duplicate samples within soil mapping units collected prior to biosolids application in 1999.
[4]EC, electrical conductivity
[5]SAR, sodium adsorption ratio
[6]No data

Treatment effects and interactions were generally significant at each sampling date in 2001 with regard to soil salinity and sodicity (data not shown). In 2002, treatment interactions were not significant, except for tillage x soil mapping unit without a consecutive biosolids application (data not shown). The following results will focus on treatment effects with regard to soil EC, SAR, and NH_4-N concentrations (Fig. 1).

Minimum tillage significantly increased soil salinity and sodicity that ranged from 3 to 6 dS m^{-1} and 4 to 9, respectively (Fig. 1A and B). In contrast, continuous tillage reduced soil EC and sodicitiy that ranged from 1 to 2 dS m^{-1} and from 4 to 6, respectively. In 2001, lint yields were significantly reduced in a minimum tillage system if soil-mapping units contained at least 25% clay (Table 2). In contrast, minimum tillage increased cotton lint yields 1179 to 1307 lbs A^{-1} on Harkey loam.

Table 2. The impact of soil mapping unit and tillage system on lint yields, 2001.

Soil Mapping Unit/Tillage System	Lint Yield
	lbs /A
Continuous Tillage	
Tigua Silty Clay	1868
Harkey Loam	1179
Glendale Silty Clay Loam	2047
Glendale Silty Clay	1670
Minimum Tillage	
Tigua Silty Clay	471
Harkey Loam	1307
Glendale Silty Clay Loam	1264
Glendale Silty Clay	--[1]

[1]--, no data

Soil mapping units significantly impacted surface soil salinity and sodicity that ranged from < 1 to 10 dS m^{-1} and from 2 to 10, respectively (Fig. 1D and E). Tigua silty clay (Tg) accumulated significantly more salts, in particular Na^{+} in comparison to other soil mapping units. Inter-season soil operations alleviated surface salinity and sodicity. In contrast, surface salinity was reduced in Glendale silty clay loam (Ge) and Harkey loam (Ha) soils (Fig. 1D). Soil EC was < 1 dS m^{-1} and below baseline levels prior to biosolids applications. Glendale silty clay (Gs) tended to accumulate slightly more salts than loamy textured soils. Surprisingly, biosolids incorporation significantly reduced surface sodicity from an average of 7 to a range of 3 to 5 in all mapping units in 2001, except in Tg. Without additional biosolids amendment in 2002, sodicity gradually increased and ranged from 4 to 9.

Bed position is typically critical to salt assessment, since the wetting front from furrow irrigation moves soluble salts to the center and tops of beds where crops are often planted (Longenecker and Lyerly, 1974). Therefore, the greatest impact of biosolids conditioning would be evident on crop beds. In this study, soil EC was significantly higher on the top of beds and increased to 6 dS m^{-1} indicative of salt hazard at the end of the 2001 growing season (Fig. 1G). Inter-season soil operations reduced surface salinity on beds to levels $\leq$ 3 dS m^{-1}. In 2002, salt accumulation across the bed surface was more uniform. However, surface salinity was > 1.7 dS m^{-1}, the soil EC prior to biosolids applications. Soil SAR at different bed locations ranged from 4 to 8.5 over a 2-yr period and was significantly lower in furrows during the 2001 growing season (Fig. 1H). After 2002 pre-plant soil operations, soil SAR similar to soil EC was uniform across cotton beds.

Treatments had no affect on NH_4-N concentrations in surface soil (Fig. 1C, F, and I). Peaks in NH_4-N at the end of 2001 growing season were indicative of N mineralization from biosolids. The increase in biosolids mineralization also coincided with increases in soil salinity and sodicity regardless of treatment. However, NH_4-N concentrations at most accounted for 10 % of soil EC.

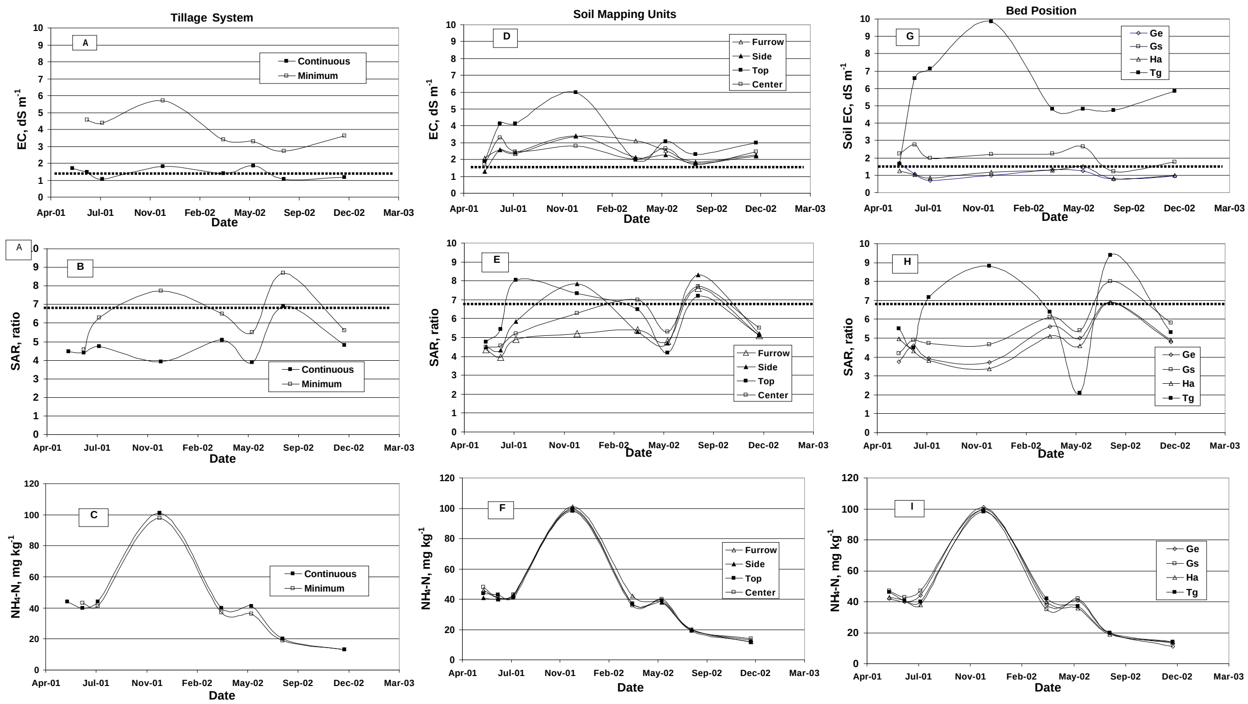

Figure 1. The effects of tillage system, soil mapping units, and bed position on surface soil electrical conductance (EC), sodium adsorption ratio (SAR), and ammonium nitrogen (NH_4-N) concentrations on field soils amended with biosolids at Ft. Hancock, TX. Horizontal dashed lines indicate soil conditions prior to field application of biosolids.

Conclusions

Organic matter enrichment using biosolids was an incomplete salt management strategy. Regular cultivation in combination with biosolids application was necessary to prevent salt accumulation, particularly on the top of furrow-irrigated beds and in clayey-textured soils. Conversely, biosolids additions effectively decreased soil sodicity regardless of tillage system. Biosolids mineralization products appear to replace Na^+ at soil exchange sites. Ammonium mineralization accounted for < 10% of soil EC and did not significantly contribute to electrical conductance.

The results of this 2-yr study indicate that biosolids shows a potential to condition soils for minimum tillage. However, greater biosolids loading rates and dual and/or rotational tillage systems need further investigation. The use of EC measurements to monitor salinity in biosolids-amended soil needs also needs further evaluation.

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