EFFECT OF IRRIGATING COTTON WITH TREATED SEWAGE EFFLUENT ON SOIL PROPERTIES AND DEEP DRAINAGE IN A VERTISOL

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Abstract

As irrigation water availability decreases, many farmers have considered using treated sewage effluent as a source of water. While treated sewage effluent contains large amounts of nitrogen and phosphorus, it also has high concentrations of sodium salts. Consequently, if not managed carefully, salinity and sodicity can increase. The objective of this study was to evaluate if gypsum application had any effect on soil quality changes in a Vertisol due to irrigating with treated sewage effluent. The experiment was located near Narrabri, Australia. The treatments were application of 2.5 t/ha of gypsum in June 2000 or an untreated control. Water quality was evaluated in samples taken from the head ditch. Soil changes in nitrate-N, $EC_{1:5}$, soil organic carbon and exchangeable cations to a depth of 1.8 m were evaluated between June 2000 and September 2003 and deep drainage was inferred with the chloride mass balance method between September 2001 and late January 2002. Effluent water was moderately saline, and compared with river water, had higher concentrations of Na, nitrate-N and K, and lower concentrations of Ca and Mg. Irrigation with treated sewage effluent caused large increases in nitrate-N, small increases in exchangeable Mg, Na and K, and small decreases in SOC. Salinity increased only in the 0.1-0.6 m depth. Gypsum application resulted in lower nitrate-N accumulation by 2003 but did not affect any other soil property or deep drainage between September 2001 and late January 2002.

Additional Keywords: water quality, sodicity, salinity, cracking clay, haplustert

Introduction

As availability of irrigation water decreases due to a combination of drought and legislation, many cotton growers have considered using alternative sources of water for irrigation. One such alternative is "grey" water or treated sewage effluent. Treated sewage effluent contains large amounts of nitrogen and phosphorus which can be used by the crop. It can also contain moderate to high amounts of salts, particularly sodium salts. Consequently, if not managed carefully, salinity and sodicity in a field irrigated with treated sewage effluent may increase. Options for controlling salinity and sodicity in irrigated cotton systems of Australia are commonly gypsum or lime. The objective of this study was to evaluate whether gypsum application could minimise sodification and salinization of a Vertisol irrigated with treated sewage effluent.

Materials and Methods

Experimental site

The experiment was established in 2000 at "Federation Farm", near Narrabri, NW NSW (149°47'E, 30°13'S). The hottest month is January (mean daily maxima and minima of 35 °C and 19 °C, respectively) and July the coldest (mean daily maxima and minima of 18 °C and 3 °C, respectively). Mean annual rainfall is 593 mm. The soil was classified as a fine, thermic, montmorillonitic, Typic Haplustert (Soil Survey Staff 1996). Federation Farm, which is irrigated with stored rainfall runoff and treated sewage effluent produced at Narrabri Shire Council's sewage treatment plant, commenced operating in May 2000. Prior to this the land was under rainfed pasture. The experimental treatments were: gypsum applied at a rate of 2.5 t/ha in June 2000 and an untreated control, arranged in a 3 RCB design across 3 adjacent fields, with each field being designated as a replicate (Petersen 1994). Individual plot size was 24 m by 400 m. In June 2000 mean particle size distribution in the 0-0.6 m depth was 50% clay, 14% silt, 36% sand; pH (in 0.01M $CaCl_2$) was 7.3 and soil organic C (SOC) 0.63 %. A cotton-wheat rotation was sown with minimum tillage on 2-m beds in all plots. Wheat was sown directly onto old cotton beds at a rate of 35 kg/ha after slashing cotton stalks and shallow bed cultivation to control heliothis moth pupae. Between harvesting the wheat in December and sowing the next cotton crop in October the land was kept in fallow with weeds being controlled by herbicides. Land preparation for cotton consisted of incorporating wheat residues into the beds and reforming of beds. Commercial cropping practices (mechanised land preparation, chemical application, harvesting, aerial application of pesticides and defoliants etc.) used in local cotton production systems were followed, with all field operations being performed by the co-operating farmer. N Fertiliser was not usually applied as nitrate concentration in irrigation water (Table 1) was deemed to be sufficient to meet cotton and wheat requirements. All crops in the cropping sequences were irrigated by furrow irrigation at a rate of 1 ML/ha when rainfall was insufficient to meet crop water use. Consequently irrigation interval ranged from once every 7-20 days during the cotton phase in summer to once every 2-6 months during the wheat phase in winter.

Soil cores (50-mm i.d.) were extracted to a depth of 1.8 m from each plot at intervals of 50-m in diagonal transects using a tractor-mounted soil corer on 12 June 2000, 20 September 2001, 29 January 2002 and 9 September 2003. The cores were divided into depths of 0-0.1m, 0.1-0.3 m, 0.3-0.6 m, 0.6-1.2 m and 1.2-1.8 m, weighed and gravimetric soil water content determined on sub-samples to estimate oven-dried bulk density. Air-dried soil (< 2 mm) was used to determine electrolytic conductivity in a 1:5 soil:water suspension (Rayment and Higginson 1992) and exchangeable Ca, Mg, K and Na with an atomic absorption spectrophotometer after washing with aqueous alcohol and aqueous glycerol to remove soluble salts followed by extraction with alcoholic 1M NH_4Cl at a pH of 8.5 (Tucker 1985). Nitrate-N was measured with a nitrate electrode after extraction with 2M K_2SO_4 (Keeney and Nelson 1982). Total SOC) was determined by the wet oxidation method of Walkley and Black on air-dried soil < 0.5 mm diameter (Rayment and Higginson 1992). The cations in the 0-1.8 m depth were expressed in t/m^2, SOC in kg/m^2 and nitrate-N in g/m^2 by multiplying the values for each depth interval by its bulk density and the depth increment, followed by summing up all the depth intervals. The soil sampled during September 2001 and January 2002 was analysed for chloride by titrating with $AgNO_3$ (Rayment and Higginson 1992). A steady state chloride mass balance model with anion exclusion was used to determine deep drainage, with a correction factor being used to account for dilution due to seasonal rainfall (Rose *et al.* 1979; Slavich *et al.* 1995). Water was also sampled during the 2001-02 cotton season from the head-ditch, and analysed for EC_w, pH_w, nitrate-N with a nitrate probe calibrated with the Kjeldahl method, and Ca, Mg, K and Na with an atomic absorption spectrophotometer (Rayment and Higginson 1992). All data were analysed using linear regression except for deep drainage which was analysed with analysis of variance after log transformation.

Results and Discussion

Water quality during the 2001-02 cotton season

Treated sewage irrigation water was alkaline, and initially, moderately saline and sodic. As the season progressed, however, alkalinity, salinity and sodicity increased markedly (Table 1). This is probably because treated sewage water was diluted with winter rainfall during the early part of the cotton season, whereas undiluted treated sewage effluent was used later on in the season. Relatively high amounts of sodium were also added in irrigation water. The amounts of Ca and Mg were much lower than that added in bore and river irrigation water typical of the lower Namoi, whereas Na was higher. Potassium was also higher (between 2-3 times) than that in bore and river. Nitrate-N was also high, between 2 and 8 times higher, even allowing for the urea applied as fertiliser. In summary, compared with traditional water sources, treated sewage effluent appears to be a good source of N and K but is more saline and sodic.

Table 1. Quality of treated sewage effluent used for irrigation during the 2001-02 cotton season. Water was sampled from the head ditch. Nutrient entry to the field was calculated on the basis of an irrigation rate of 1 ML/ha. (EC_w, electrolytic conductivity of the water; SAR, sodium adsorption ratio).

Irrigation date	pH_w	EC_w (dS/m)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Na (kg/ha)	SAR	NO_3-N* (kg/ha)
15 Oct. 2001	8.8	0.7	3.4	13.6	6.4	91.7	5.1	26.8
23 Dec. 2001	8.7	0.7	9.1	11.9	7.2	151.8	8.5	50.3
21Jan. 2002	8.9	0.7	4.7	8.0	3.7	78.5	5.7	29.7
30 Jan 2002	8.7	0.7	15.5	13.0	7.7	172.2	9.3	46.2
18 Feb. 2002	9.2	1.1	8.9	11.2	6.1	119.3	7.1	56.6
8 March 2002	9.7	1.4	7.7	6.6	5.8	122.7	8.4	36.8
seasonal sum			49.2	64.3	36.9	736.2		246.5

*130 kg of N/ha was applied in the form of a dry application of urea on 15 December 2001.

Deep drainage between September 2001 and February 2002

Deep drainage out of the 1.8 m depth was not affected by gypsum application. Mean deep drainage was 32 mm in gypsum-treated plots and 27 in the control plots.

Changes in soil properties between June 2000 and September 2003

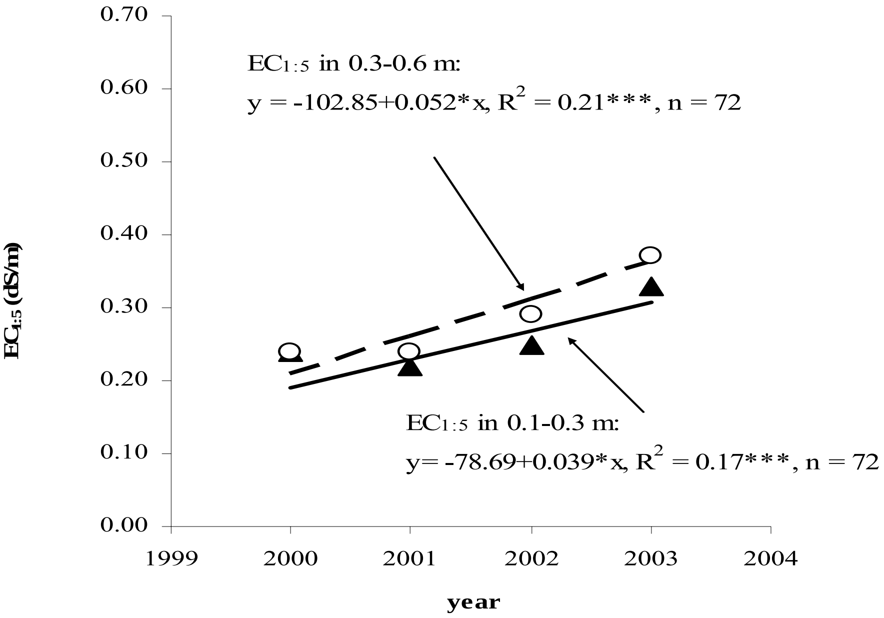

Fig. 1. Changes in $EC_{1:5}$ in the 0.1-0.3 m (▲) and 0.3-0.6 m (○) depths between June 2000 and September 2003

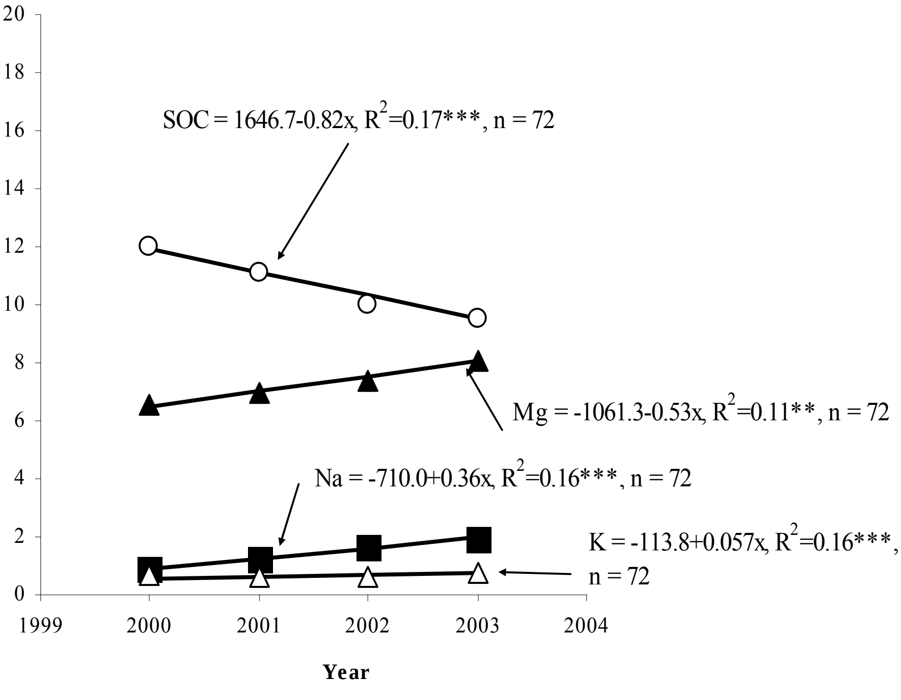

Fig. 2. Changes in exchangeable cations and SOC between June 2000 and September 2003

$EC_{1:5}$ in the 0-0.1 m, 0.6-1.2 m and 1.2-1.8 m depths did not change with either time or gypsum application. Mean $EC_{1:5}$ was 0.23 dS/m in the 0-0.1 m depth, 0.32 dS/m in the 0.6-1.2 m depth and 0.37 dS/m in the 1.2-1.8 m depth. Significant increases did occur with time however, in the 0.1-0.3 m and 0.3-0.6 m depths but not with gypsum application (Fig. 1). These increases were significantly correlated (R^2 = 0.35***, n = 144) to the increases in nitrate-N which took place at the same time (see later discussion). Exchangeable Ca was unaffected by both time and gypsum. Mean exchangeable Ca in the 0-1.8 m depth was 11.1 t/m^2. Exchangeable Mg, K and Na, and SOC in the 0-1.8 m depth were unaffected by gypsum application. The exchangeable cation contents, however, increased with time and SOC decreased (Figure 2). The R^2 values although statistically significant are relatively small, and imply that the observed changes are minimal. Furthermore variability in data was relatively high. Coefficients of variation were 22% for Mg, 22% for K, 55% for Na and 28% for SOC. In addition, with respect to Na it is also because a major part of the increase occurred in the surface 0.1 m (R^2 = 0.62***, n = 72) and less so in the subsoil. In contrast to the changes in cations and SOC, nitrate-N in the soil profile increased markedly with time, although gypsum application resulted in a slower rate of accumulation (Fig. 3). Linear regression analysis indicated that the slopes of the fitted lines differed significantly ($P < 0.01$). Although gypsum had no significant effect on deep drainage between September 2001 and January 2002, the lesser rate of nitrate-N accumulation in gypsum-treated plots suggests that it may have had some beneficial effects on subsoil structure and, consequently increased drainage and nitrate leaching by 2003. Figure 3 also suggests that the effect of gypsum application on nitrate-N accumulation manifested itself only in 2003. This may be related to a general deterioration in soil structure as mean dispersion index in the 0-0.6 m depth increased from 5.1 g/100g in 2002 to 9.5 g/100g in 2003, an increase of 86% (Hulugalle, unpublished data). The increase in profile nitrate-N with time in all plots also suggests that the present cropping system of cotton-wheat may not be utilising all the N supplied in the treated sewage effluent.

In summary, irrigation with treated sewage effluent resulted in small increases in exchangeable Mg, K and Na, small decreases in SOC and substantial accumulation of nitrate-N in the 0-1.8 m depth. In the long-term if these trends continue significant soil structural deterioration due to decreasing Ca:Mg and SOC, and increasing ESP is likely. Some deterioration appears to have already occurred. Structural deterioration may be minimised by "shandying" of effluent with rainfall or river water, more frequent application of gypsum and use of polyacrylamide (PAM). N accumulation in the soil could be reduced by including a cereal forage crop such as forage sorghum or a grass pasture phase in the rotation to increase N extraction. The extracted N could then be exported off-farm as hay.

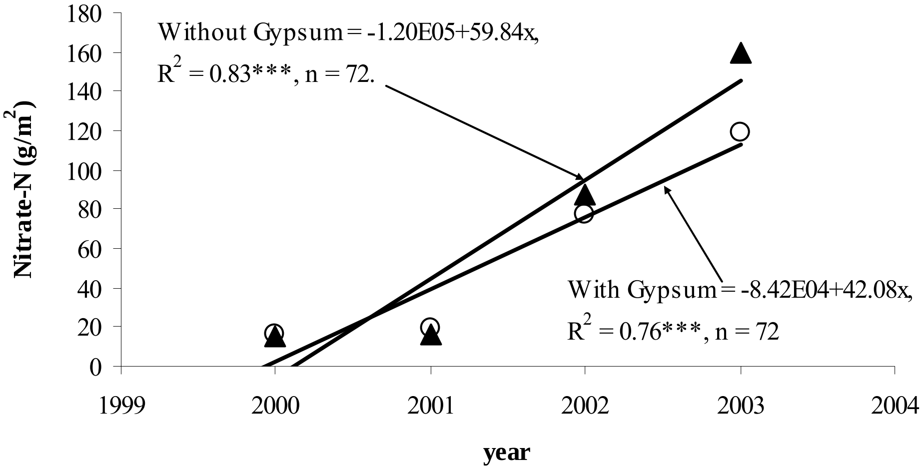

Fig. 3. Changes in nitrate-N in the 0-1.8 m depth between June 2000 and September 2003 with (○) and without (▲) gypsum application

Conclusions

Effluent water was moderately saline, and compared with river water, had higher concentrations of Na, nitrate-N and K, and lower concentrations of Ca and Mg. Irrigation with treated sewage effluent caused large increases in nitrate-N, small increases in exchangeable Mg, Na and K, and small decreases in SOC. Salinity increased only in the 0.1-0.6 m depth. Gypsum application resulted in lower nitrate-N accumulation by 2003 but did not affect any other soil property or deep drainage between September 2001 and late January 2002.

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