TEMPORAL SODIUM FLUX IN A WOODLOT SOIL IRRIGATED WITH SECONDARY TREATED EFFLUENT: THE IMPLICATIONS FOR SUSTAINABLE IRRIGATION AND SOIL MANAGEMENT

by

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CERTIFICATION

I, Steven Andrew Lucas, certify that the substance of this thesis has not been submitted for any degrees and is not currently being submitted for any other degree or qualification. I certify that any assistance received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

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Steven Andrew Lucas Date

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ABBREVIATIONS, ACRONYMS AND SYMBOLS

Abbreviation	**Term**
Δ	symbol prefix for “change in “
θ	volumetric soil moisture
θ_g	gravimetric soil moisture
cmol(+)/kg	centimole per kilogram pertaining to cationic charge
C_{TH}	threshold concentration
C_{TU}	turbidity concentration
CEC	cation exchange capacity
CI	confidence interval
C	final concentration (solubility curves)
Co	initial concentration (solubility curves)
D	deep drainage
DDL	diffuse double layer theory
EAT	Emerson Aggregate Test
EC	electrical conductivity (dS/m)
EP	equivalent populations
ESP	Exchangeable Sodium Percentage
ΔESP	change in soil ESP
ET	evapotranspiration
FC	field capacity
ΔI	irrigation surplus/deficit
ΔCI	cumulative irrigation surplus/deficit
ICP-AES	inductively coupled plasma atomic emission spectrometer
IL	interception loss
Ksat	saturated hydraulic conductivity
meq/L	milliequivalent per litre
mmol/L	millimole per litre
OS	outside solution
PET	potential evapotranspiration

PVC	polyvinylchloride
Q_p	precipitation
Q_e	applied effluent
R	runoff
R_d	retardation factor (solubility curves)
RSD	relative standard deviation
SAR	Sodium Adsorption Ratio
SAR_p	Sodium Adsorption Ratio for soil in 1:5 distilled water
STE	secondary treated effluent
WP	wilting point
WWTW	wastewater treatment works

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ABSTRACT

This study reports results obtained and the approach taken in investigating the temporal sodium flux in a woodlot soil receiving secondary treated effluent at Branxton, NSW. Previous research has shown woodlot soils receiving secondary treated effluent undergo an increase in exchangeable sodium percentage (ESP) over time. Increased soil ESP influences micro-aggregate/soil pore stability and, particularly when subject to irrigation waters of specific low-electrolyte concentrations, results in decreased soil permeability and a subsequent need to reduce effluent application rates.

Therefore, in irrigated woodlot soils it has been necessary to implement strategies to remove excess sodium from the root zone to maintain optimum permeability of the receiving soil, that is, maintaining the cation balance (as soil ESP) to promote optimum soil pore size. To maintain optimum permeability, an understanding is needed of temporal variations in the accumulation/leaching (flux) of sodium within a soil under secondary treated effluent irrigated conditions. The ability to define the sodium flux depends on the frequency of soil sampling and the ability to interpret the net loss/gain in soil sodium in relation to the applied hydraulic load over time. Past research has measured changes in soil ESP on an annual basis, or longer, making it impossible to interpret temporal sodium flux within a given year.

The rate of change of soil ESP has ramifications for optimum permeability within an effluent irrigated woodlot. With respect to increasing/decreasing soil ESP, a major response of the clay particles within micro-aggregates is the deformation of conducting soil pores and reduced hydraulic conductivities. In addition, clay dispersion is governed by the soil ESP and electrolyte concentration of the infiltrating waters at the time, where dispersed clay particles may block conducting soil pores and further reduce hydraulic conductivity. Therefore, investigating the temporal sodium flux in conjunction with the temporal variation in electrolyte concentration of infiltrating waters will give greater insight into the response of effluent irrigated soils to sodium-rich waters over time.

Three research aims were formed to investigate temporal sodium flux. These include:

1. To investigate trends in the dominant water balance components for a woodlot soil receiving secondary treated effluent (STE);
2. To examine temporal and spatial variation in both the water balance components and measured soil properties, particularly the sodium flux; and
3. To investigate the implications of the sodium flux on the loss of soil structure and drainage over time (dispersion events), particularly in relation to temporal changes in soil ESP and effluent SAR.

Monitoring programs for water balance components and soil parameters covered the period January 2002 – October 2003. Every two months, soil samples were taken at designated sites and at different depths (10, 20, 40, 60, and 80 cm). These samples were analysed for exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), from which the ESP values were derived. Also, this appears to be the first time that soil sampling at this frequency, which enables the temporal sodium flux to be determined, has been carried out.

Column leaching experiments were also performed over the study period to illustrate the response of the woodlot soil, in terms of micro-aggregate stability, to hydraulic loads of varying SAR. Column leaching experiments also confirmed the rate of solute movement through the soil profile and the woodlot soil's ability to bind/exchange sodium under different hydraulic loads and electrolyte concentrations. Soil extraction plate methods were used to determine wilting point and field capacity for these soils.

The Sodium Adsorption Ratio (SAR), which is the solutional equivalent to soil ESP, was used to define the electrolyte concentration of the applied effluent and rainfall to the woodlot. The net loss/gain of exchangeable sodium (ΔESP) at different depths and times was determined and compared with changes in water balance components and the measured volumetric soil water (θ) over time. The soil water surplus/deficit was recorded at a daily time-step and a cumulative approach was used to determine the long-term soil water surplus/deficit. In addition, variations in groundwater levels were monitored to observe if surplus irrigation events were reflected in temporal trends.

As a result of determining the temporal variation in soil ESP, effluent and rainfall SAR, daily soil water deficit/surplus (short-term), cumulative soil water deficit/surplus (long-term) and volumetric soil moisture, temporal trends are presented. The sodium flux was then investigated by interpreting trends in the monitored data with respect to the dominant water balance components. All parameters were then used to model the potential dispersive behaviour of the receiving soil over time and depth, in relation to the volume and electrolyte concentration of the effluent and rainfall applied over time. The implications for soil structure and permeability depend on variations in soil ESP and effluent SAR.

Results from this research show that soil ESP varied by as much as 24 % over a four-month period and is shown to be a function of the sodium loading (from STE) and soil water surplus/deficit. On each sampling occasion, soil ESP generally increased with depth at all irrigated sites. Soil ESP at non-irrigated sites was much lower than irrigated sites, although the variability in soil ESP was much greater. Variations in SAR of the waters received by the woodlot soil (effluent and rainfall) over the study period ranged from 0.5 to 5.9. It is shown that the SAR range, coupled with variations in soil ESP, has ramifications for maintaining long-term soil structure. Soil structure at different sites within a woodlot will respond differently according to the soil ESP/effluent SAR relationship.

The dispersive potential of soil at a given ESP receiving irrigation waters of known SAR was assessed in light of the relationship between soil ESP and effluent SAR. This showed the dynamic response of effluent irrigated soils to the long-term temporal variation in electrolyte concentration of rainfall/effluent. The relationship between soil ESP and effluent SAR is graphically presented as a continuum, which in turn can be used as a management tool for assessing the potential for dispersion of clay particles in a soil of known ESP and irrigated with waters of known SAR. By identifying trends in the temporal sodium flux, the *optimum* permeability of the receiving soil can be assessed in relation to the electrolyte concentration of the applied waters and the soil exchangeable sodium percentage (ESP).

Secondary treated effluent application rates can then be corrected to prevent "dispersive" irrigation events over the long term and/or management strategies applied to remove excess sodium from the soil profile. The significance of the research is that a better understanding of the temporal dynamics of sodium in the soil profile will allow improved management of effluent irrigated woodlots, with the aim of making the practice sustainable with respect to controlling accumulating soil sodium and maintaining soil structure for future landuse.