沙漠研究 **24**-1, 109-112 (2014)
Journal of Arid Land Studies

Land Application of Municipal Wastewater to Desert Ecosystems

- Case Studies Identifying Risks and Opportunities -

John G. MEXAL*[1], Geno A. PICCHIONI[1], Manoj K. SHUKLA[1], April L. ULERY[1] and William C. LINDEMANN[1]

Abstract: Slow rate land application (SRLA) of treated wastewater is a low-cost alternative to conventional wastewater treatment plants and has been in place in high rainfall areas as a method of further treating wastewater and utilizing the nutrients for non-food crop production. In arid lands, a SRLA system recycles nutrients, conserves fresh water resources, recharges groundwater, and reduces surface water contamination. However, a SRLA system must balance the beneficial use of water and nutrients against the application of excess contaminant nutrients and salts. Practical guidelines for the SRLA of treated wastewater in arid and semiarid regions are lacking, *vis a vis* soil responses serving as 'metrics' assessing vulnerability to degradation and loss of productivity or biodiversity. We present two case studies of SRLA to desert ecosystems: Primary treated wastewater to short-rotation woody crops in Ojinaga, Chihuahua, Mexico; and secondary treated wastewater to a desert shrub ecosystem in Las Cruces, New Mexico. Wastewater applications were monitored for up to seven years to evaluate vegetation and soil responses, and changes in groundwater quality were assessed in Ojinaga. All wastewaters had relatively low nitrogen content and no nitrate-N was found below the root zones. However, chloride did move below the root zone, and into groundwater at the Ojinaga site. Soil salinity increased with wastewater application, and irrigation uniformity strongly influenced soil quality and plant response. Increasing effluent sodicity may encourage encroachment by sodium-tolerant plant species, and cause shrub injury. SRLA systems with high salinity or sodicity need to consider tradeoffs in the management of wastewater.

Key Words: Biodiversity, Biomass, Groundwater, Leaching, Salinity

1. Introduction

Land application of wastewater is a recommended method of recycling nutrients and organic matter while protecting fresh water resources (USEPA, 1996). Wastewater has been applied to agronomic crops, rangelands, forests, recreation areas, and disturbed lands (Sopper *et al.,* 1982). As wastewater moves through the soil profile, the soil and plants act as filters that trap and treat waste particles and contaminants allowing the remaining water to drain. The benefits of this system are both the effective remediation of wastes and the recycling of water, nutrients, and carbon via biomass production (Bastian and Ryan, 1986).

A land application system, ideally, should have low capital inputs and operating costs and be easy to maintain. Unfortunately, there is limited information to guide land managers in fragile arid and semiarid environments where wastewater may be the only source of supplemental irrigation. A land application system design requires balancing the input of water required by plants against the amount of nitrogen that can be applied without adverse environmental impact (Metcalf & Eddy Inc, 1991; WPCF, 1990). The wastewater application rate is governed by the total amount of nitrate-N allowed to enter the groundwater.

Salt loading is not incorporated into the design equations; however, excess soluble salt accumulation in the rhizosphere reduces plant growth. To use the limited and potentially saline wastewater, land managers must balance wastewater quality, crop water usage, nitrogen (fertilizer) requirements, and future soil salinization. Presently, there are no environmental impact data, such as groundwater contamination, salt and nutrient deposition, soil salinization, and vegetation stress data that could aid in the design and operation of sustainable wastewater land application practices.

Land application could mitigate environmental degradation of the Rio Grande (Doremus, 2008), provide financial benefits to area communities seeking low-cost wastewater treatment, and sustain the natural vegetation if managed properly. The following case studies explore the use of saline wastewater for pulpwood, wastewater treatment and disposal in arid regions (**Table 1**).

2. Las Cruces, New Mexico, USA

The 4-year study site (32º18'N, 106º55'W) is semiarid

* Corresponding Author: jmexal@nmsu.edu
Box 30003, MSC 3Q, Las Cruces, NM 88003
1) Department of Plant and Environmental Sciences, New Mexico State University

(Received, September 9th, 2013; Accepted, December 2nd, 2013)

Table 1. Selected site characteristics of wastewater utilization studies.

Parameter	Las Cruces, NM, USA	Ojinaga, Chi, Mexico
Soil texture	Sand	Clay loam
Soil depth	3 m (to caliche layer)	3 m (to groundwater)
Irrigation	Sprinkler	Flood
Species	*Larrea tridentata, Prosopis glandulosa*	*Eucalyptus camaldulensis*
TDS (mg L^{-1})	1,900-2,800	1,950-2,220
BOD (mg L^{-1})	40	29-43
TKN (mg L^{-1})	10-19	14-37

with an average rainfall of 220 mm with approximately 50% of the annual rainfall occurring between July and September. The annual mean temperature is 15.8ºC with monthly temperatures varying from 5.5ºC in January to 26.6ºC in July. The potential evapotranspiration (PET) of the site is 1,800 mm. The City of Las Cruces applies secondary treated industrial wastewater through a fixed head sprinkler system onto native Chihuahuan Desert vegetation including creosote bush, *Larrea tridentata* (DC.) Cov.; mesquite, *Prosopis glandulosa* (Torr.); and annual and perennial forbs and grasses. Shrub cover was 23% with the remaining as open intershrub spaces. Wastewater total salinity (TDS) reached ≈3,000 mg L^{-1}, comprised mostly of sodium, chloride and alkalinity. Total nitrogen applied to the site from 2002 to 2005 was 264 kg ha^{-1}.

By 2003, effluent irrigation increased sodium adsorption ratio of the soil extract (SARe) under intershrub spaces to 22.5 cm depth (**Fig. 1**). Thereafter, all irrigated sites had elevated SARe down to at least 45 cm. By the end of the study, surface SARe ranged from 26 to 35 at all sites. Even though the increases in SARe diminished with depth, they were elevated at 105-195 cm under the shrubs by 2005, a pattern not observed under the intershrub spaces (Picchioni *et al*., 2012a).

Salt loading was a function not only of the wastewater concentration, but also the uniformity of irrigation. Unfortunately, irrigation uniformity was poor (**Fig. 2**). Areas with the highest application rate had the highest surface SARe levels (Adhikari *et al*., 2012). Uniformity and amount of irrigation are critical components of a sustainable land application system as physical attributes of the soil profile may change along with the chemical components (Babcock *et al*., 2009). Successful irrigation requires scheduling tools as well as sufficient wastewater to meet the needs of the standing biomass (Al-Jamal *et al*., 2002; Ruiz *et al*., 2005; Saucedo *et al*., 2006).

The wastewater application did increase plant growth, especially the herbaceous species (Picchioni *et al*., 2012b). On the non-irrigated plot, herbaceous dry matter reached 64 and 73 g m^{-2} with relatively high rainfall in 2004 and 2005, but was only 14 g m^{-2} with low annual rainfall in 2002. Increased

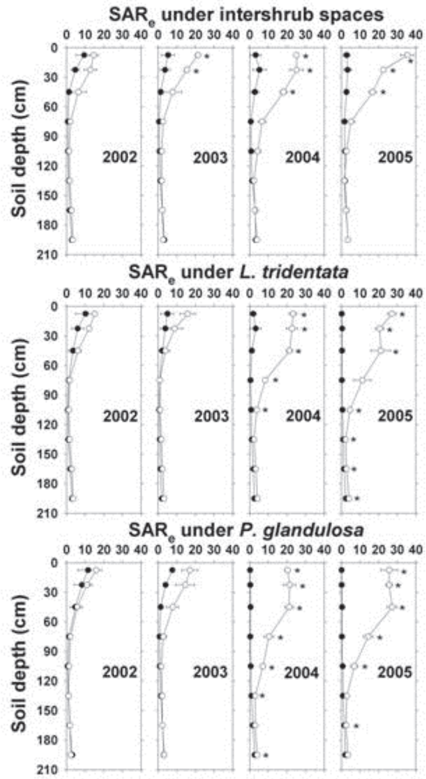

Fig. 1. Soil saturation extract sodium adsorption ratio (SARe) under intershrub space, *L. tridentata* and *P. glandulosa* on non-irrigated (●) and irrigated plots (○). SAR calculated as $Na^+/Ca^{2+} + Mg^{2+})1/2$, all ion concentrations in mmol L^{-1} (Picchioni *et al*., 2012b).

rainfall increased herbaceous species diversity on the non-irrigated plot. Unlike the non-irrigated plot, the irrigated plot experienced progressive increases in herbaceous biomass, but a general decline in species richness. The irrigated plot averaged 57, 97 and 145 g m^{-2} in 2002, 2004 and 2005, respectively. For further details, see Picchioni *et al*. (2012a, b). Microbial activity and diversity were not directly affected by effluent irrigation. The proximity to vegetation (mesquite) was more important than effluent on soil biology (Mattes, 2010).

3. Ojinaga, Chihuahua, Mexico

Ojinaga is located at the confluence of the Rio Grande and Rio Conchos on the U.S. - Mexico border (29.6ºN, 104.4ºW). The climate of this part of the Chihuahuan desert is arid, with an annual rainfall of less than 250 mm with 75% falling between June and October, and an annual PET of 2,450 mm. The maximum temperature is 50ºC, with a minimum temperature of -10ºC.

Municipal sewage is piped into a 60,000 m^3 single-cell -anaerobic lagoon, serving as a settling pond for separating the solids from the waste stream and providing some reduction in waste strength. The lagoon reduces BOD, TSS and fecal coliform (FC) to some degree. Primary-treated wastewater

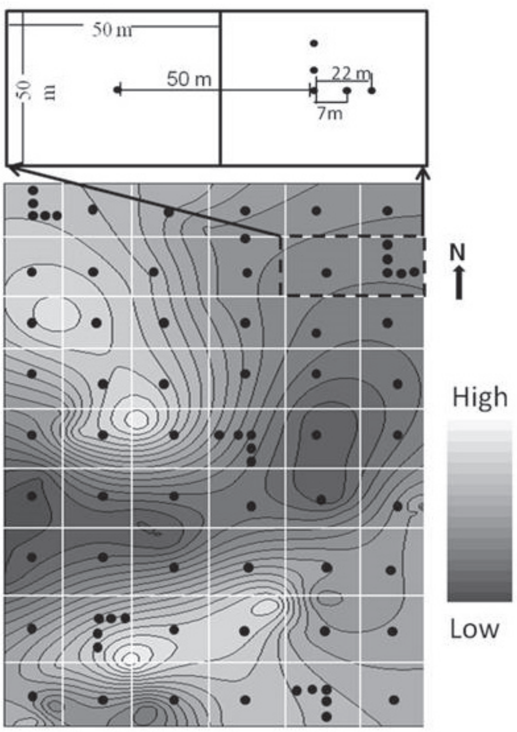

Fig. 2. Contour map of wastewater application and sampling locations (Adhikari *et al*., 2012).

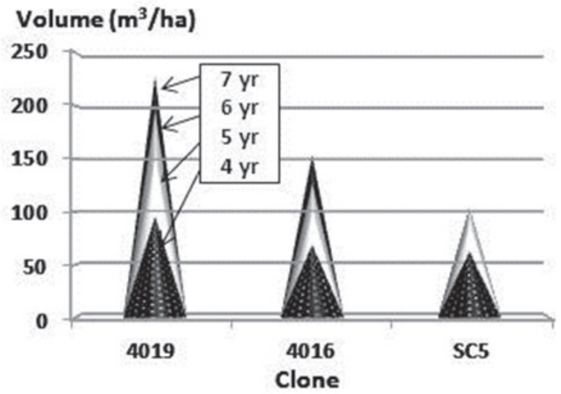

Fig. 3. Volume production of three clones of *Eucalyptus camaldulensis* for years 4 through 7 after planting (Tena Vega *et al*., 2005).

flows to the land application unit for final treatment and disposal. A land application site was established in April 1997 with three clones of eucalyptus [*Eucalyptus camaldulensis* (Dehnh.)]. Monitoring included wastewater effluent and groundwater quality characteristics, soil properties, and plant growth.

After 7 years, there was minimal impact to groundwater with neither fecal coliform contamination nor an increase in nitrate-N. However, there was a 10% increase in groundwater salinity caused by high transpiration of the crop trees. Survival was excellent (>90%) and growth averaged 3.0 m yr^{-1} in the early years (Tena Vega *et al*., 2005). The best tree selection was *Eucalyptus* clone 4019 producing over 220 m^3 ha^{-1} or over 30 m^3 ha^{-1} yr^{-1} (**Fig. 3**).

Table 2. Characteristics to serve as metrics in arid zone SRLA systems.

Parameter	Method	Unit
Texture	Hydrometer	NA
Soil depth	Trench/ Auguring	cm
Infiltration	Tension Infiltrometer	cm d^{-1}
Salinity	Saturated paste extract EC or TDS	dS m^{-1}, mg L^{-1}
Sodicity	Saturated paste extract Na, Ca, Mg	SAR
pH	pH Electrode	NA
Nitrate-N	1:5 KCl extract	mg L^{-1}
Phosphate-P	$NaHCO_3$ extract	mg L^{-1}
TKN	Colorimetry	mg L^{-1}
BOD	Respirometry	mg L^{-1}

4. Implications

In addition to the suggested soil and wastewater properties listed in **Table 2**, potential metal or other contaminants specific to the SRLA site should also be monitored. Irrigation uniformity must be improved in addition to using the highest infiltration rate to predict drainage of nonreactive components to the groundwater. Evaluate plant cover and species over time if you are concerned about encroachment of invasive species or loss of indigenous plants which may be sensitive to specific salts found in the wastewater. Deliberate planting of productive, non-food agroforestry species that are tolerant to the SRLA site conditions may provide maximum utilization of wastewater resources as well as providing a commercial product and improving the local economy (Tena Vega *et al*., 2005; Vallotton *et al*., 2000).

These wastewater land application case studies are located in arid regions with low annual precipitation and high evapotranspiration. Consequently, applied water must be balanced against the needs of the plant and salt and nutrient loading to ensure the development of a sustainable system. The applied wastewater must meet the plant's water use needs while preventing nutrient leaching to groundwater and salinity increases in the rhizosphere.

Additionally, waste streams containing heavy metals are potentially problematic, as their behavior in soil profiles may be influenced by other wastewater constituents (Nemmers *et al*., 2013). Wastewater can be used to produce an economic crop, providing income and employment opportunities; but tradeoffs may be required. If the objective is to maintain native plant diversity, limiting sodium loading may be required. If the objective is to produce income, limitations on waste inputs may be required. If the objective is to maximize wastewater attenuation by aggressive sodium-tolerant plant species, high sodium effluent may be beneficial. The goals of the system need to be incorporated into the process.

References

Adhikari P., Shukla M.K., Mexal J.G. (2012): Spatial variability of infiltration rate and sodium content of desert soils: implications for management of irrigation using treated wastewater. *Trans. ASABE*, **55**: 1711-1721.

Al-Jamal M.S., Sammis T.W., Mexal J.G., Picchioni G.A., Zachritz W.H. (2002): A growth-irrigation scheduling model for wastewater use in forest production. *Agric.Water Manage.*, **56**: 57-79.

Babcock M., Shukla M.K., Picchioni G., Mexal J., Daniel D. (2009): Chemical and physical properties of Chihuahuan desert soils irrigated with industrial effluent. *Arid Lands Res. Manage.*, **23**: 47-66.

Bastian R.K., Ryan J.A. (1986): Design and management of successful land application systems. *Proceeding of the utilization, treatment, and disposal of waste on land*. Soil Sci. Soc. Amer., Madison, WI. p. 217-234.

Doremus D. (2008): Rio Grande salinity management-A real possibility? *Southwest Hydrol.*, **7**(2): 24-25.

Mattes M. (2010): *Soil microbial activity and diversity as affected by wastewater effluent application.* M.S. Thesis, New Mexico State University.

Metcalf & Eddy Inc. (1991): *Wastewater Engineering: Treatment, Disposal, and Reuse.* McGraw Hill: New York, New York. 815 p.

Nemmers S.J., Ulery A., Shukla M.K. (2013): Sorption and mobility of arsenic in desert soils when applied with municipal wastewater effluent. *New Mexico Academy of Science*, **44**: 137-148.

Picchioni G.A., Shukla M.K., Mexal J.G., Babcock M., Ruiz A., Sammis T.W. (2012a): Land application of treated industrial wastewater on a Chihuahuan desert shrubland: implications on water quality and mineral deposition. *Arid Land Res. Manage.*, **26**(3): 211-226.

Picchioni G.A., Mexal J.G., Shukla M.K., Ruiz A., Babcock M., Daniel D.L., Rodriquez D.S. (2012b): Land application of treated industrial wastewater on a Chihuahuan desert shrubland: impacts on the natural vegetation. *Arid Land Res. Manage.*, **26**(4): 312-327.

Ruiz A., Sammis T.W., Picchioni G.A., Mexal J.G., Mackay W.A. (2006): An irrigation scheduling protocol for treated industrial effluent in the Chihuahuan Desert. *J. Amer. Water Works Assoc.*, **98**: 122-133.

Saucedo D., Sammis T.W., Picchioni G.W., Mexal J.G. (2006): Wastewater application and water use of Larrea tridentata. *Agric.Water Manage.*, **82**: 343-353.

Sopper W.E., Seaker E.M., Bastian R.K. eds. (1982): *Land Reclamation and Biomass Production with Municipal Wastewater and Sludge.* The Pennsylvania State University Press, University Park, PA.

Tena Vega M., Mexal J., Barragan G., Rubio H.O., Sosa C.M. (2005): Wood production utilizing raw sewage in Ojinaga, Chihuahua, México. *In* Kungolos A.G., Brebbia C.A., Beriatos E. eds., *Sustainable Development and Planning II. Vol. 1. WIT Trans. Ecol. Environ. Vol. 84.* WIT Press. p. 593-599.

U.S. Environmental Protection Agency (USEPA). (1996): *US-Mexico Border XXI Program Framework Document.* 160-R-96-003. EPA: Washington, D.C.

Vallotton A.D., Mexal J.G., Vallotton D.G., Erickson C., Iglesias L., Jessen B., Nuñez R., Picchioni G., Samani Z., Zachritz II W.H. (2000): Sustainable use of wastewater for small communities: A model system for short rotation woody crop production, *In* Westerhoff P. ed., *The U.S.-Mexican border environment: Water issues along the U.S.-Mexican border. Southwest Center for Environmental Research and Policy Monograph Series No. 2.* San Diego State University Press. p. 47-71.

Water Pollution Control Federation (WPCF) (1990): *Natural Systems for Wastewater Treatment.* Water Pollution Control Federation, Alexandria, Virginia. 270 p.