A SOIL COLUMN STUDY OF THE IMPACT OF MUNICIPAL EFFLUENT IRRIGATION ON TWO MANITOBA SOILS

by

Chittaranjan Ray

A thesis
presented to the University of Manitoba
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ABSTRACT

Changes in chemical and some physical properties of the Roblin and the Erickson soils were studied on soil columns in a greenhouse under simulated average year and dry year rainfall and simulated day length period for the growing season in Roblin, Manitoba.

Historical weather data were used to simulate the rainfall in an average year and in a dry year. Theoretical day length hours for the growing period in Roblin were obtained from meteorological tables. Evapotranspiration demand of brome grass in the greenhouse was compared with that expected in field conditions.

The physical changes in the soil columns were measured in terms of bulk density, water stability index of soil aggregates and the amount of root mass. The chemical changes were measured in terms of the major and minor nutrient concentration, pH and salinity in the individual horizons of the soil columns.

The water stability index of the soil aggregates was reduced considerably. Bulk densities of individual horizons did not change significantly. Salinity and pH of the soil horizons increased. Concentration of major nutrients changed in most of the cases. The Sodium Adsorption Ratio (SAR) of the saturation extracts of each soil horizon increased substantially. Trace element concentration did not change substantially. Concentration of boron and manganese was higher in the leachates as compared to that in the effluent.

Average crop yield was of the order of 3.0 tonnes per hectare per cut. A linear relationship was observed between the amount of effluent applied within the evapotranspiration range of the crop and the yield of dry matter. The plant tissues were slightly deficient in nitrogen and phosphorus.

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Chapter I

INTRODUCTION

The practice of irrigating using municipal sewage effluent is becoming more and more popular due to the success in both crop production and wastewater disposal. The increasing public awareness and participation in clean environment protection has been the key force behind new attitudes to land treatment systems.

Land application of lagoon-treated wastewater has been considered as a tertiary treatment process in terms of the removal of pollutants from the wastewater by the soil matrix before reaching the groundwater body. The present approach to land disposal is more scientific in comparision to the old "out of sight out of mind" approach. Land application of wastewater whether for disposal per se, or for crop irrigation, has been proven to be most convenient and economical in small communities.

There are, however, some problems connected with effluent irrigation on the Canadian prairies. The wide variation in seasonal rainfall from year to year results in variable irrigation and effluent application requirements. Many farmers on the prairies still follow the practice of summer fallowing. Farmers participating in a wastewater irrigation project are bound by certain conditions, such as pumping out a certain minimum volume of effluent from the lagoon every summer. Under such circumstances, the farmers may have to apply some effluent on the fallow land.

The purpose of this study was to determine the changes in the chemical and some physical properties of two Manitoba soils with and without crop cover, after one season of irrigation using municipal effluent. This study was done using soil columns of the Roblin and the Erickson soils which are the characteristic soils of the Roblin area. Individual horizons of both the soils up to a depth of 1.0 m were taken from the field and were rebuilt in pre-fabricated plywood boxes according to the field bulk densities. To this end soil columns of the two soils were exposed in a greenhouse to rainfall regimes likely to occur in a dry and in an average year respectively, with supplemental effluent irrigation.

The two rainfall regimes for simulation purposes were determined using historic weather data for the Roblin area and probabilistic methods. The combination of cropped (brome grass) and fallow land, and dry and average year regimes, resulted in four different treatments as follows:

A - fallow, average-year rainfall

B - fallow, dry-year rainfall

C - grassed, dry-year rainfall

D - grassed, average-year rainfall

The above letter designations have been used in the thesis for the various treatments. Each treatment was replicated five times and, therefore, there was a total of twenty soil columns of each Roblin and Erickson soils respectively, for an overall total of forty soil columns.

effluent, municipal wastewater, wastewater, effluent, and sewage water are used interchangeably in this report accordingly. Similarly, the terms land treatment, land disposal, land application, and wastewater renovation are considered as equivalents.

Chapter II

RELATED RESEARCH

2.1 CASE STUDIES

Land application of sewage water was practiced by the ancient Romans and Greeks. However, the earliest well documented sewage farm was established in Edinburgh, Scotland in 1650 (U. S. Environmental Protection Agency (EPA), 1978). In the same publication a clear description of the development of sewage effluent irrigation projects in the United Kingdom and the United States, since 1840, can be found. Further, according to Tietjen (1975)

> Braunsweig was one of the German towns which followed the examples in England where in about 1843, at Edinburgh, Ashburton, or Devon, the first sewage fields were established for the two fold purpose of keeping the rivers clean and manuring the soil.

Thomas (1973) says

> Land disposal of collected urban water dates back at least four centuries, and some of the systems presently in use began operation before the turn of the 20th century. Historically, the purpose of land treatment approaches has emphasized wastewater disposal, whereas the current trend is away from the concept of disposal and toward the concept of treatment and/ or reuse. .... We are in the midst of an evolution from an 'out of sight out of mind' land disposal approach to a scientifically oriented treatment and/ or reuse system.

Egeland (1973) discussed the success of land disposal of wastewater against various constraints. According to him

> In the short span of four years, the practice of land disposal has been raised from near extinction to a position of national eminence. .... Fortunately, the wastewater technology professionals continue to meet the crisis of the day and

> proceed methodically toward the goal of selective separation and useful recycling of wastewater resources. Demeaned by the Senate committee, discredited by the army, maligned by the youthful consumer advocates, ridiculed in the popular journals and hampered by a lack of adequate research funds, these professionals are nevertheless hammering out a standard pollution profile and seem to be on the verge of dramatic breakthroughs in their quest for methods of treatment that will be ecologically beneficial and economically profitable, and which will place minimum demands on the nation's natural and energy resources.

Today, there are more than 3000 land application systems in the U. S. A. and some have been effective for more than half a century. These systems use various types of wastewater such as domestic, food processing, animal, petroleum and other different origins. Loehr et al. (1979a) have described 14 existing land application projects in Australia, the United Kingdom and the United States.

McKim (1979) reported on the world wide developments of land treatment systems. According to him, in Poland, sewage represents over 50 percent of all the surface water flow during dry years. Therefore, application of sewage to grassland and fodder and root crops is necessary not only because of its fertilizer value but because it is the only water available for irrigation. He also describes the development of sewage farming in Iran, Chile, Soviet Union, and India in the form of range irrigation, forage and crop irrigation and aquaculture.

Feinmesser and Wikinski (1979) reported that in Israel, a total of 4409 ha was under effluent irrigation in 1978 out of which about 73 percent was used for growing field crops. As reported by Lau (1979), effluent can be applied as suplemental water for furrow irrigation of sugarcane in Hawaii without detriment to groundwater quality and sugar yield. Further, for the irrigation of bermudagrass on golf courses, effluent irrigation is a feasible means of water conservation and wastewater disposal.

A significantly large number of projects in the U. S. A. are operating successfully. The Bakersfield project in California handles 50 ML day^{-1} (13 million U. S. gal per day) of wastewater and irrigates 560 ha (1400 ac) of cropland (Uiga, 1978). Surface irrigation method is used to apply the wastewater to corn, cotton, alfalfa, and barley. Referring to the Lubbock project of Texas (Gray, 1977), a participating farmer says that presently 2000 ha (5000 ac) of diverse crops is under effluent irrigation. Other well known projects such as Muskegon county in Michigan and University Park in Pennsylvania, are also working successfully.

Canadian experiences with land application of wastewater has been very limited. Oldham (1979) says

> Climatic conditions, although they do not preclude such land application, cause the acceptability of the method to be severely reduced when compared with many areas of the USA. Severe winter conditions in Central and Eastern Canada impose very basic restrictions on the length of the irrigation season, while the amount of precipitation on the West Coast imposes limitations on the amount of liquid that can be applied per unit land area.

According to him, there are three wastewater irrigation projects in British Columbia which use wastewater from food processing. In Ontario, the wastewater is mostly of industrial origin and a major portion of this wastewater comes from the food processing industry. Horgan (1980) describes the design and the installation of the Landsdowne project in Ontario and says that the success of this particular project will encourage other municipalities to install new and even larger systems.

In Western Canada, the practice of municipal effluent irrigation is hardly 20 years old. Fig. 2.1 shows the distribution of licensed effluent irrigation projects on the prairies. The irrigation potential, ownership, and the year of development for the individual projects are shown in Table 2.1. All these projects except for Medicine Hat use sprinkler irrigation. The Medicine Hat project uses the border dike method. The Roblin project uses a combination of sprinkler and gated pipe irrigation.

2.2 SUITABILITY OF EFFLUENT FOR IRRIGATION

Municipal wastewater has the characteristics of both irrigation water and fertilizer. A high liquid content of 99.9 percent shows its comparability to irrigation water from natural sources. However, its chemical characteristics determine its potential for irrigation. Bouwer and Chaney (1974) reported that effluents in general are considered as cheap source of irrigation water without taking into account their high nutrient content and in particular their high nitrogen content.

The concentration of soluble salts is an important factor in land treatment of wastewater and the electrical conductivity (EC) is an accurate measure of the soluble salt concentration in wastewater. According to Stewart and Meek (1977), about 700 ppm of NaCl in wastewater can result in 1 mS cm^{-1} of EC. The Ca content in wastewater alters this value to some extent.

Another important parameter in estimating salt effects of wastewater on soils is the Sodium Adsorption Ratio (SAR) as it considers the presence of other exchangeable cations such as Ca and Mg. Alberta

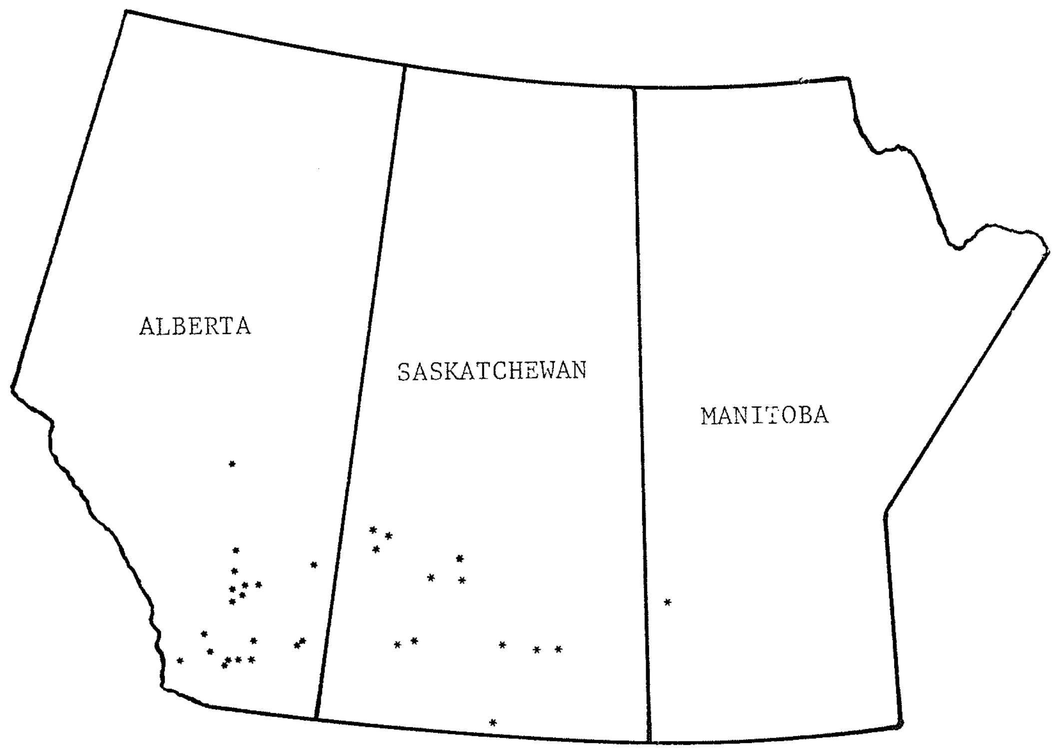

Fig. 2.1 Distribution of municipal effluent irrigation projects on the Canadian Prairies.

Table 2.1 Effluent Irrigation Systems on the Canadian Prairies

Province and System	Irrigable Area (ha)	Ownership	Developed (year)
ALBERTA			
Bowden	2	town	1979
Calgary	75	city	1975
Clareshom	60	private	1976
Coaldale	50	private	1976
Cowley	7	private	1976
Crossfield	20	private	1978
Edmonton Subdivision	40	private	1975
Esso Service Station	2	private	1974
Granum	14	private	1970
Lethbridge Air Port	10	Government	1978
Medicine Hat	90	private	1965
Okatoks	50	private	1976
Oyen	20	private	1977
Rockyford	10	private	1979
Springbank Air Port	10	Government	1978
Strathmore	64	private	1979
Taber	155	town	1970
(INDUSTRIAL)			
Medicine Hat Fertilizer	60	private	1977
Vauxhall Food Processing	100	private	1970
Carseland Ammonia Plant	270	private	1975
Lakeside Meat Packers	130	private	1975
Lethbridge Rendering	20	private	1975
SASKATCHEWAN			
Balgonie	53	private	1976
Biggar	91	private	1982
Coronach	82	private	1981
Davidson	21	private	1974
Etonia	43	private	1974
Gull Lake	22	private	1976
Maidstone	48	private	1974
Marshall	21	town	1982
Moose Jaw	1485	city	1982
Neilburg	25	private	1972
Swift Current	759	private	1979
Wolesley	77	private	1976
MANITOBA			
Roblin	64	private	1982

Environment (1977) in its guidelines for municipal wastewater irrigation, suggest that effluent with a SAR higher than eight is considered unsatisfactory and wastewater with an EC of 2.5 mS cm^{-1} or greater should also be considered unsuitable unless the soil to which it is applied is very well drained. Small wastewater irrigation projects with effluent which has a high SAR and low EC can possibly be made suitable by modifying the water quality by adding gypsum. However, in South Africa (Hayman, 1977) it was observed that $FeSO_4$ worked better than gypsum in terms of crop yield when added to effluent with high sodium content. The U. S. Environmental Protection Agency standards for a 20-year application period as reported by Reynolds et al. (1979) suggest a SAR value less than four to be suitable for crop irrigation. According to the same source, the permissible ranges for some other constituents and characteristics are as follows:

pH : 4.5 to 9.0

Total dissolved solids : 500 mg L^{-1} to 1000 mg L^{-1}

Electrical conductivity : 0.75 mS cm^{-1} to 1.50 mS cm^{-1}

Chlorides : 5 meq L^{-1} to 40 meq L^{-1}

A number of other sources {Jame and Nicholaichuk (1979), Ayers and Westcot (1976), and Shainberg and Oster(1978)} discuss the salinity problems. In general, the authors have suggested the inclusion of a leaching fraction in irrigation water in order to flush the salts out of the root zone. However, authors like Hook and Kardos (1978) have shown that excess leaching of wastewater adds more pollutants to groundwater and the loss of nutrients becomes excessive.

It was found that to maintain a steady-state salt profile the concept of leaching fraction is very important. Bernstein and Francois (1973) showed that a steady-state profile could be reached very slowly especially when the leaching fraction is low. Using saline effluent (EC = 2.0 mS cm^{-1}) with a leaching fraction of 0.062, about 20 irrigations were required (total water application of 3250 mm) to achieve a steady-state condition. According to the same authors, a steady-state profile cannot be achieved with zero leaching fraction and salts will continue to accumulate imposing severe limitations to plant growth till they finally precipitate. The authors have pointed out that when a crop is irrigated with effluent with applications using a small leaching fraction, steady-state salinity profile tends to develop and the salinity gradually increases from the surface to the bottom of the root zone. The level of salinity at the surface is controlled by the salinity of irrigation water and the level at the bottom of the root zone is primarily determined by the leaching fraction. As the crop uptake of moisture is mainly from the upper layers of the soil where the salt concentration is the lowest, a lower leaching fraction can be used without fear of significant reduction in crop yield.

Ayers and Westcot (1976) in their previously referenced publication gave clear guidelines for the quality of water suitable for irrigation. The effluent used for crop irrigation should satisfy the same criteria.

Gilley (1976) stated that municipal wastes contain significant amount of major plant nutrients. However, some wastes, because of unfavourable physical characteristics or toxic chemicals, are not suitable for irrigation. Even desirable chemicals (plant nutrients) can become undesirable if added in excessive amounts. Proper management practices are highly essential even if the effluent is highly suitable for crop irrigation and more so if it is least suitable.

The Clean Environment Commission of Manitoba (1979) has specified the required quality of irrigation water (Table 2.2) and any effluent used for irrigation should meet the stipulations of the guidelines.

2.3 LAND TREATMENT PROCESSES

2.3.1 Selection of Process and Design of System

The two principal criteria in the selection of the type of land treatment system and in its design are the potential to minimize environmental pollution and the maintenance requirement of the system under the given conditions.

Bouwer and Chaney (1974) say that the choice of system is mainly controlled by the soil, hydrogeological conditions and by the availability of land. The U. S. Environmental Protection Agency (EPA), (1977) classifies the land treatment systems into three major groups. They are

1. Slow-rate or crop irrigation
2. Rapid infiltration
3. Overland flow

In a slow-rate system, vegetation is the critical component in managing the load of water and nutrients. This is the most common land treatment practice. Rapid infiltration is an approach by which a significantly large portion of wastewater applied to land infiltrates the soil surface, percolates through the pores of the soil and recharges

Table 2.2 Irrigation Water Quality Standards for Manitoba[1]

Items	Units	Maximum Limits
Electrical Conductivity	$mS\ cm^{-1}$	up to 1.0 - safe 1.0 to 2.0 - possibly safe more than 2.0 - hazardous
Filtrable Residue	$mg\ L^{-1}$	up to 700 - safe 700 to 1400 - possibly safe more than 1400 - hazardous
pH	units	5.0 to 9.0
As	$mg\ L^{-1}$	0.1
B	$mg\ L^{-1}$	0.3
Cd	$mg\ L^{-1}$	0.01
Cu	$mg\ L^{-1}$	0.2
Pb	$mg\ L^{-1}$	5.0
Ni	$mg\ L^{-1}$	0.2
Zn	$mg\ L^{-1}$	2.0
Cr	$mg\ L^{-1}$	0.05
Ca	$mg\ L^{-1}$	*
Mg	$mg\ L^{-1}$	*
Mn	$mg\ L^{-1}$	0.2
Fe	$mg\ L^{-1}$	5.0
Na	$mg\ L^{-1}$	*
F	$mg\ L^{-1}$	1.0
NO_3-NO_2-N	$mg\ L^{-1}$	30.0
Cl	$mg\ L^{-1}$	350
SO_4-S	$mg\ L^{-1}$	400
Co	$mg\ L^{-1}$	0.05
Sodium Adsorption Ratio (SAR)	-	up to 4 - safe 4 to 8 - possibly safe more than 8 - hazardous

NOTE:

$$* \quad SAR = \frac{0.043\ Na}{(0.025\ Ca + 0.04\ Mg)^{0.5}}$$

[1] Reproduced from 'Report on Proposal Concerning Surface Water Quality Objectives and Stream Classification for the Province of Manitoba', by the Clean Environment Commission, Revised Edition, May 1979.

the groundwater. In this case, evapotranspiration is a negligible portion of the effluent loading rate. Overland flow is the process by which the wastewater is renovated by physical, chemical and biological means when the wastewater is allowed to flow in a thin sheet down a relatively impermeable soil. This is a relatively new approach. The objectives of this process are wastewater treatment and, to a minor extent, crop production. This method can also be used for the production of forage grasses and the maintenance of open spaces and green belts. Kemp et al. (1979) compared the slow-rate system and the overland flow system. Both systems have their own advantages and limitations.

Schrauben (1981) reported the presently followed irrigation methods in the rural communities of Michigan. They are:

1. Border irrigation
2. Sprinkler irrigation
   a) Solid set
   b) Side roll
   c) Center pivot
3. Gated pipe overland flow irrigation
4. Drip irrigation (orchard, forest etc.)

Sheaffer (1978) describes the six basic components of the land treatment system employed to manage and to use the wastewater. They are:

1. Transportation of wastewater to the application site.
2. Pre-treatment facility to avoid the spreading of raw sewage on land. The levels of Biochemical Oxygen Demand (BOD), suspended

solids, and the coliform bacteria should not exceed the EPA specifications.

3. Storage for non-use periods.
4. Irrigation site where crops can be grown.
5. "Living filter" which includes crops and soils and where herbage remove the nutrients.
6. Subsurface drainage system, which can be either natural (an area of groundwater recharge) or installed drain tiles.

2.3.2 Soil Factors affecting Effluent Irrigation

Soil works as a treatment medium in the land treatment system. In such a system, the wastewater is not "disposed of", but rather the nutrients from wastewater are retained in the soil, removed by plants or passed through the soil to groundwater. The potential for prolonged irrigation of soil by sewage effluent depends upon soil properties such as texture, structure, infiltration capacity, available water holding capacity (AWC), permeability and cation exchange capacity (CEC) (Loehr et al. 1979b). In addition to the above-mentioned soil properties, Sheaffer (1978) considers a few more properties such as total organic nitrogen, total organic carbon, exchangeable Ca, Mg, Na, and K, total soluble salts, and bulk density. Biological, chemical and physical mechanisms work to renovate wastewater after its application to soil.

Soil texture describes the size distribution of mineral particles and soil structure describes the organization of individual particles. These variables can be linked to the conduction of water in the soil.

Infiltration rate depends upon soil permeability, moisture content and topography. The available water holding capacity refers to the micropore water which plant roots can extract from the soil. Thus essentially, it is the water storage capacity of the soil. A high available water holding capacity increases the residence time of wastewater in the soil, thus promoting renovation of wastes (Loehr et al., 1979b).

The cation exchange capacity is a rough index of the ion interchange between charged particles of the nutrients in wastewater and the clay and colloidal fraction of the soil. The cation exchange capacity of the soil varies greatly depending upon the amount and type of clay present and the amount of organic matter (Brady, 1974). A high soil CEC indicates a higher potential for wastewater renovation.

Soil pH exceeding 8 indicates the impact of Na in water. In heavy metal removal, a moderately high pH is considered to be an essential and desirable factor (Sheaffer, 1978).

Phosphate is another concern in soil from a pollution point of view. It is held by Ca at pH above 6 and by Fe and Al at pH below 6. The content of $CaCO_3$ in soil is very important in wastewater renovation as it is a buffer against heavy metals and phosphate. Still, according to Sheaffer, one percent of $CaCO_3$ in soil would certainly hold 6500 ppm of Zn or 1900 ppm of P in separate instances.

Organic carbon in soils is responsible for increasing the CEC of soils. The ratio of total organic nitrogen to total organic carbon in the top 60 cm of soil profile should be of the order of 10:1 to 12:1. Any reduction in this ratio causes greater likelihood of liberating ammonia.