African Journal of Agricultural Research Vol. 6(16), pp. 3747-3754, 18 August, 2011
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR11.510
ISSN 1991-637X ©2011 Academic Journals

Full Length Research Paper

Soil salinity in irrigated fields used for urban agriculture under a semi-arid environment of South Africa

S. A. Materechera

Faculty of Agriculture, Science and Technology, North West University (Mafikeng Campus), P/B X2046, Mmabatho, 2735, South Africa. E-mail: 20560915@nwu.ac.za.

Accepted 22 July, 2011

The study quantified the salinity in profiles of urban agriculture soils irrigated using sprinkler, basin and drip methods for 15 years compared with rainfed conditions. The ANOVA showed significant influence ($p < 0.05$) of both irrigation methods and soil depth on the amount of soluble salts, pH and electrical conductivity (ECe) of the soils. Irrigation methods significantly increased ($p < 0.05$) the salt concentration (mg/kg) within the profile compared to the control for Ca^{2+} (792 vs 464), Mg^{2+} (398 vs 196), K^{+} (274 vs 164), Na^{+} (19.3 vs 9.8), pH (7.13 vs 6.3) and ECe (22.1 vs 7.9 dS/m). Except for Na, the concentrations of Ca, Mg and K were higher in the top than subsoil layers while pH and ECe were not significantly different. Basin irrigation had consistently accumulated highest amounts of Ca, Mg, K and Na followed by drip and sprinkler method. The pattern for pH and EC was basin > drip > sprinkler > control. Sprinkler irrigation was the only method which showed increased pH and ECe at 10 to 20 cm compared to 0 to 10 cm depth. It was concluded that irrigation was increasing salinity in the soils and points to the need for adherence to sound irrigation water management practices especially appropriate irrigation scheduling.

Key words: Crop production, irrigation water quality, salt accumulation, urban agriculture, root zone salinity, semi arid areas.

INTRODUCTION

South Africa is generally a water stressed country and it can largely be classified as semi-arid due to low rainfall and high evaporation (DWAF, 2002). As a result, South Africa's water resources are, in global terms, scarce and limited in extent (Water Research Commission, 1994). According to DWAF (2002), irrigated agriculture consumed by far the most water in South Africa compared with other economic sectors. They estimated that by 2010, irrigation would use about 46% of the available water resources followed by domestic use (17%), estuaries and lakes (10%), industry (11%), forestry and mining (7%) and other uses (9%).

The lack of adequate water resources in agriculture, especially in arid and semi-arid areas, is forcing many growers worldwide to use water with relatively high salt concentration to irrigate crops (De Clercq et al., 2009; Ould Ahmed et al., 2010). As was noted by Keremane and McKay (2006) that provision of water needed to feed a growing population, and balancing this with all the other demands on water, is one of the greatest challenges of this century. The tensions between supply and demand for water are likely to be aggravated by climate change since some areas will receive higher rainfall, while most of the currently water-scarce regions will become drier and warmer (Perry et al., 2009). This concern over the effect of climate change on water resources requires that water should be used more efficiently and effectively in irrigated agriculture in order to increase and sustain crop productivity in arid and semi-arid areas, especially (Bates et al., 2008). Various studies have shown differences in the efficiencies of different irrigation methods and their impact on soil salinity and crop yields (Sharmasarkar et al., 2001; Malash et al., 2005; Houk et al., 2006; Hassanli et al., 2010).

Urban agriculture is farming that is practiced in urban or peri-urban centers. It is a dynamic concept that comprises a variety of livelihood systems ranging from subsistence production and processing at household level to fully commercialized agriculture (Van den Berg and Van Veenhuizen, 2005). As is the case with many sub-Saharan African countries, the intensity of urban agriculture in South Africa has increased over the past 15 years (Van den Berg and Van Veenhuizen, 2005). Urban agriculture can have both negative and positive effects on the health and environmental conditions of the urban population and the associated natural resources (Lock and Van Veenhuizen, 2001).

The negative effects of irrigation-induced soil salinity and sodicity on crop yields have been well documented (Gale, 1975; Cetin and Bilgel, 2002). Crop production can suffer when salts accumulate in the soil root environment by increasing the osmotic potential of the soil solution which decreases a crops ability to extract water and results in suppressed plant growth and decreased yield (Shalhevet, 1994). Soil salinization due to irrigation has threatened the productivity and sustainability of irrigated agriculture for centuries (Hillel, 2000). Worldwide, estimates suggest that crop production losses associated with salinity on irrigated lands are around US$11 billion annually and increasing (Ghassemi et al., 1995).

In addressing the complexities of land reform in the post-apartheid South Africa, the Government has made provision for allocation of commonage land, largely peri-urban land, to poor residents in order to help with local economic development (South African Government, 2001). Mafikeng is the capital city of the North West Province with a population growing at a rate of 9.3%. According to the City Council of Mafikeng (1999), there are about 560 ha of land under 23 farms being irrigated by small-scale and emergent commercial farmers in the urban and peri-urban areas of the city of Mafikeng. The crops grown by these farmers principally involve vegetables and fruits. The fields vary in size from 0.15 to 3.5 ha. In 2008, the distribution of the irrigation methods among the 23 farms was: sprinkler (27%), basin (23%), drip (22%), furrow (15%) and bucket (13%).

Irrigation induced soil salinization is negatively affecting agricultural production in many parts of the world and requires close monitoring and control (Maas and Grattan, 1999; Houk et al., 2006). A soil salinity problem manifests when the salt buildup in the root zone is significant enough that loss in crop yield results (Szabolcs, 1989). Soil salinity negatively affects crop growth by increasing the osmotic potential of the soil solution (Jones and Marshall, 1992). Due to the semi-arid nature of Mafikeng, irrigation has become an important component of crop production systems in urban and peri-urban areas of the city. Low rainfall and high evaporation in Mafikeng means that irrigation has and will continue to play an important socio-economic role for the people through the practice of urban agriculture.

This study was prompted by concerns from both municipal officials and farmers, that repeated irrigation for many years may have lead to gradual build up of salinity in the soils and thus affecting the quality of soil and yields of crops (City Council of Mafikeng, 1999). Hitherto, there have been no attempts to quantify the soil salinity in fields under various irrigation methods being used for urban agriculture in and around the city of Mafikeng. There are four fields located close to each other, within the fringes of Mafikeng City, being irrigated with water from the same underground source for the past fifteen years. This setting provided an opportunity to assess the influence of the irrigation on salt accumulation in the soil profile. Such knowledge would assist the City Council to design and recommend appropriate management options for salinity control in the fields being used for urban agriculture. The objective of the study was therefore to quantify the salinity levels in the profiles of fields that have been used for urban agriculture under three different irrigation methods for the past 15 years. Since there was no baseline data of each of the farms available to allow proper tracking of changes in salinity overtime, a field which was within close proximity but never irrigated was used for comparison (non-irrigated control).

MATERIALS AND METHODS

Location of study fields

The fields used for the study were all located within 5 km of the city of Mafikeng (25°48' S, 25°38' E) in the North West Province, South Africa. The Municipal Area slopes from 1410 m asl in the east to 1210 m asl in the west (City Council of Mafikeng, 1999). The climate at the site is typical semi-arid savanna with a mean annual summer rainfall of 500 mm. The rainfall is unreliable and highly variable in both temporal (CV = 23%) and spatial (CV = 31%) distribution. About 68% of the annual precipitation falls between November and January in relatively few heavy downpours, and there is a pronounced dry season from April to September. The rainfall is unevenly distributed over the crop growing season.

The mean monthly potential evapotranspiration (PET), temperature and rainfall for the site show that there is no time when PET is less than rainfall (Figure 1). This, coupled with high temperatures, result in high rate of potential and actual evapotranspiration and heat stress to plants (Maraka, 1987). Consequently, rainfall does not play a significant role in meeting the crop water or leaching requirements and the high evapotranspiration values also make irrigation water requirements too high. The high evapotranspiration rate in the area implies that the water applied to the fields represents a potential soil salinity hazard. The surface (0 to 20 cm) soil is a red sandy loam with 56% sand, 33% silt, 11% clay, and is classified as a Hutton form (Soil Classification Working Group, 1991). It has characteristics similar to a Ferric Luvisol (FAO-ISS-ISRIC, 1998). The soil is well drained and not waterlogged for extensive periods. The biological and chemical properties of the soil are generally suitable for the establishment and productive growth of most agronomic and horticultural crops (Soil Classification Working Group, 1991).

Field management

All the fields were established in 1994 from virgin land and have been used for producing vegetables (*Spinacia oleracea*, *Allium cepa*, *Daucus carota and Beta vulgaris*), *Vitus spp.*, *Medicago sativa* and fruits (*Citrus sinensis, Prunus persica*, *Citrus limon*). The

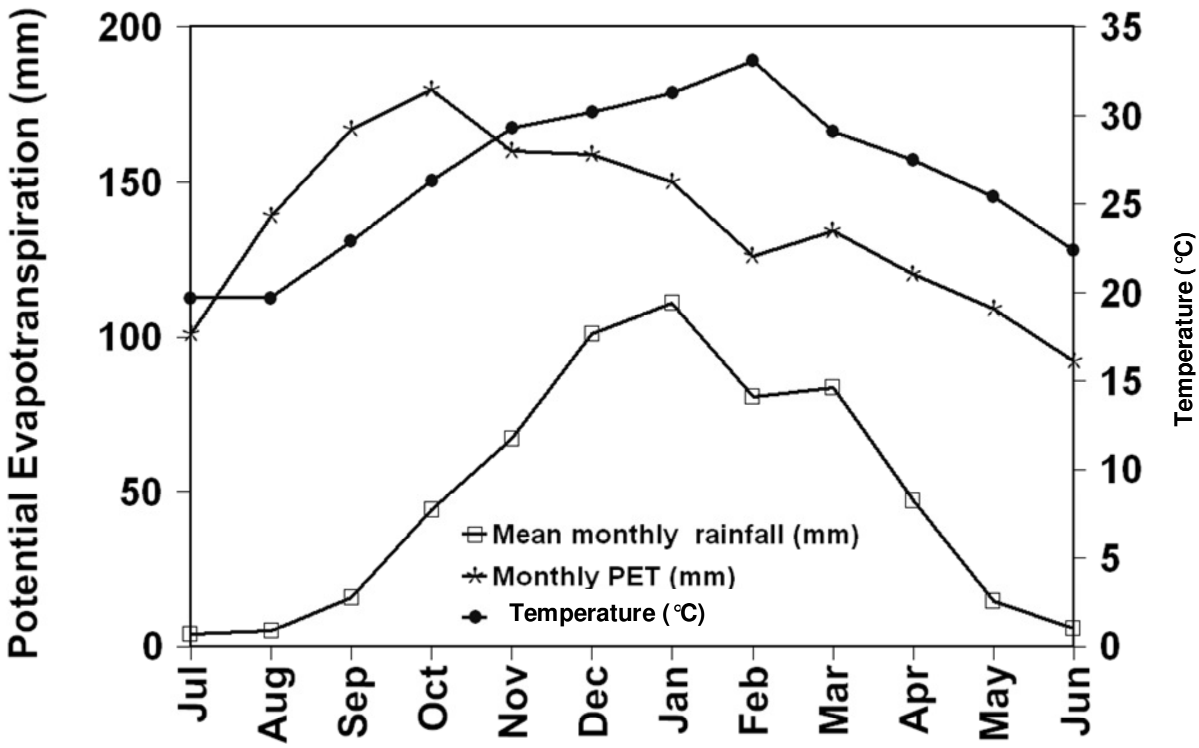

Figure 1. Long-term (15-year) mean monthly rainfall, temperature and potential evapotranspiration (PET) of Mafikeng in the North West province in South Africa. PET was calculated using a computer programme based on Penman formula originally designed by the FAO (Technical Paper No. 45) and modified to local conditions (Maraka, 1987).

fruits were all irrigated using localized basin method (about 1 m diameter basin was constructed around a fruit tree) while vines and vegetables were mostly irrigated with drip and sprinkler methods respectively. Most of the farmers depend on past experience' to schedule irrigation. Irrigation water is usually applied infrequently, as needed, and the crop utilizes a considerable portion of the available soil water (50% or more) before the next irrigation. Generally farmers irrigate fields in the mornings and late afternoons when it is cooler and convenient especially for those farmers that work at other jobs during the day. A field where crops were grown under dryland conditions over the same period was used as control.

Measurements

For purposes of statistical analysis, the four irrigation methods (sprinkler, drip, basin and control) were considered as main plots while the five sampling depths (0 to 5, 5 to 10, 10 to 15, 15 to 20 and 20 to 40 cm) in each main-plot, served as sub-plot treatments. Soil samples were collected in September 2009 using a 35 mm auger from twenty randomly selected positions within each field over an area of approximately 0.5 ha. The sampling positions within the drip and basin irrigation methods were located in the wetted zone, while in the sprinkler method they were located randomly across the field. The soil samples were air dried and sieved through a 2 mm sieve. They were analyzed for soluble salts (Ca^{2+}, Mg^{2+}, K^+, Na^+), pH and electrical conductivity (ECe) using the methods of The Non-Affiliated Soil Analysis Working Committee (1990). It was not possible to measure chlorine in the soil samples due to technical problems with the equipment. The ECe was determined on a saturated paste extract. Briefly, water was added to a soil sample in a plastic container and stirred until a glittering uniformly saturated soil-water paste was achieved. The sample was left to stand overnight and a vacuum was applied to the sample on a Buchner filter funnel to obtain a filtrate on which electrical conductivity was measured.

At the same time, five irrigation water samples were collected from each method using 50 ml plastic vials. Water samples were collected from the sprinklers, drippers and taps of the sprinkler, drip and basin irrigation methods respectively. The samples were stored in the refrigerator at 5°C and analyzed for the same properties as the soil samples.

Analysis of data

The data was analyzed as a split-plot design with farms (irrigation methods) and main plot and sampling depth as sub-plot treatments respectively**.** Data were subjected to analysis of variance (ANOVA) using the PROC GLM command of the SAS statistical package (SAS Institute Inc., 2006). The data for soil depths were pooled during analysis based on the profile locations where differences were observed. The LSD test was used to compare treatment means at P = 0.05.

RESULTS

The quality characteristics of water used for irrigating all

Table 1. Chemical properties of the water[a] used for irrigating agricultural fields among the four urban agriculture farms in the study.

$pH_{1:3}$	EC_w (dS m^{-1})	TDS (mg L^{-1})	K^+ (mg L^{-1})	SO_4^{2-} (mg L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	Na^+ (mg L^{-1})	SAR	Cl^- (mg L^{-1})	HCO_3^- (mg L^{-1})	NH_4^+ (mg L^{-1})	NO_3- (mg L^{-1})
6.8±0.3	0.31± 0.02	209.4± 7.2	4.1± 0.6	2.3± 0.1	21.3± 2.5	13.3± 0.4	12.2± 0.8	0.52± 0.03	10.3± 1.1	149.4± 0.8	0.1± 0.04	1.2± 0.6

[a]Values are means ± SD, n = 20.

Table 2. Soil salinity in four fields used for urban agriculture as influenced by irrigation methods.

Soil depth (cm)	Treatment	Ca^{2+} (mg kg^{-1})	Mg^{2+} (mg kg^{-1})	K^+ (mg kg^{-1})	Na^+ (mg kg^{-1})	$pH_{1:3}$	EC_e (dS m^{-1})
0 to 10	Irrigated	885±91	466±51	344±51	16.8±5	7.13±0.2	2.34±0.06
	Control	334±26	218±14	201±23	06.9±3	06.08±0.1	0.08±0.002
	$LSD_{0.05}$	452	197	126	5.3	0.87	1.23
10 to 20	Irrigated	728±67	329±21	204±52	21.7±4	7.03±0.3	2.1±0.033
	Control	204±14	173±11	127±9	12.6±2	6.44±0.1	0.71±0.0011
	$LSD_{0.05}$	368	87	62	5.4	0.37	0.091
20 to 40	Irrigated	543±89	342±38	122±27	48.6±3.2	7.37±0.3	1.8±0.02
	Control	174±51	87±15	65±9	8.5±1.1	6.5±0.1	0.05±0.002
	$LSD_{0.05}$	244	189	55	33.6	0.45	0.09

[a] Values are means of five determinations.

the fields used in this study are presented in Table 1. There was very little variation among the properties of the water samples from the various farms as they were all obtained from the same underground source. Although the Total Dissolved Salts (TDS) in the water was slightly higher than the recommended safe limit indicated in Table 1, the water was of considerably good quality according to the national guidelines outlined by the National Irrigation Board (ARC-IAE, 1966) and Department of Water Affairs and Forestry (DWAF, 1996). According to the guidelines for interpretation of water quality for irrigation given by Ayers and Westcot (1985), there would be no restriction to use this water for irrigation on the basis of salinity although some of the elements (K^+, Ca^{++}, Mg^{++} and HCO^-_3) were on the higher range. Generally, saline water is categorized as water with an ECw > 3.0 dS/m while sodic water is that with an SAR > 12 (Ayers and Westcot, 1985).

The results of ANOVA (not shown) indicated significant influence of both irrigation methods and sampling depth on soil salinity. There were also significant (irrigation methods x depth) interactions for most of the salinity variables. Application of the irrigation water on the soil for a 15-year period had contributed to the accumulation of signify-cantly higher ($p < 0.05$) concentration of salts, pH and EC in both the top and subsoil layers of the irrigated fields compared to control (Table 2). The trend in concentration of most salts in the soil by the irrigation methods was generally in the order basin>drip=sprinkler>control (Table 3).

The distribution of the accumulated salt, pH and EC within the soil profiles of the fields used for urban agriculture is presented in Figure 2. The pattern for the distribution of Ca^{2+}, Mg^{2+}, K^+ and Na^+ were consistent and revealed that the irriga-tion methods accumulated significantly higher ($p<0.05$) salt concentrations than the control. Basin irrigation had the highest concentration of salts in the profiles and their patterns were in

Table 3. Distribution of salt accumulation in the soils of fields irrigated by different methods under urban agriculture at Mafikeng.

Soil depth (cm)	Irrigation method	Ca^{2+} (mg kg^{-1})	Mg^{2+} (mg kg^{-1})	K^{+} (mg kg^{-1})	Na^{+} (mg kg^{-1})	$pH_{1:3}$	EC_e (dS m^{-1})
0 to 10	Control	534±17	218±11	211±9	6.8±.3	6.13±.8	0.68±0.01
	Drip	877±32	410±23	356±33	11±.8	7.2±.7	2.4±0.03
	Sprinkler	789±28	477±36	279±19	13.5±1.2	6.9±.5	1.4±0.02
	Basin	989±55	511±42	388±20	26±2.3	7.3±.6	0.2±0.01
	$LDS_{0.05}$	256	*178*	65	3.5	0.64	0.75
10 to 20	Control	393±31	173±11	127±7	12.7±1.5	6.4±.5	0.8±0.08
	Drip	547±16	251±24	211±18	16±.78	6.8±.7	1.9±0.02
	Sprinkler	596±25	233±38	149±13	15±2.4	7.2±.8	2.0±0.03
	Basin	1041±47	502±52	252±19	34±1.6	7.1±.6	2.4±0.02
	$LDS_{0.05}$	106	67	81	1.9	0.35	0.9
20 to 40	Control	214±72	132±66	106±28	14.5±2.2	6.8±.7	0.8±0.01
	Drip	432±46	187±53	138±21	17.4±1.8	6.7±.4	1.5±0.04
	Sprinkler	317±16	201±32	115±33	16.1±3.1	7.3±.4	2.2±0.02
	Basin	1123±32	412±33	241±17	31.6±1.4	6.9±.6	2.1±0.01
	$LDS_{0.05}$	88	43	10.7	2.6	0.31	0.7

[a] Values are means of five determinations ± SD.

the order basin > drip = sprinkler > control. The accumulation of Ca^{2+}, Mg^{2+} and K^{+} was higher in the top (0 to 10 cm) but decreased in the lower (10 to 20 and 20 to 40 cm) layers. A reverse pattern was observed for Na^{+}. The pH and EC in the profiles of the soil was significantly higher ($p < 0.05$) at all depths in irrigated than control fields.

DISCUSSION

The results have revealed that repeated application of irrigation water through different methods under urban agriculture in and around the city of Mafikeng in the past 15-years, have contributed to a gradual buildup of salts in the profiles of the irrigated soils compared to un irrigated ones. Salinity in the irrigated fields could also occur because of waterlogging on the soil surface due to unleveled surfaces. It was observed that some of the fields were not level and had depressions/low lying areas across the fields. These areas acted as holders of water which after evaporation left some salts on the soil surface. The presence of a hard tillage (plough) pan at a depth of 10 to 15 cm in most of the fields could further enhance the degree of soil salinity in the surface soil through impeding drainage. The importance and significance of sampling at representative sites within each irrigation method cannot be overemphasized in his interpretation. Samples collected from the wetted and non-wetted zones of basin and drip irrigation methods would give different results.

In most irrigated soils, the exchangeable sodium percent (SAR) and salinity generally tend to be lowest at the soil surface and increase with depth through the root zone (Rhoades and Merrill, 1976). In this study however, it was interesting to observe that soil salinity tended to decrease with depth for all the irrigation methods. According to Ayers and Westcot (1985) the decreasing salinity with depth is usually a strong indication of a shallow water table (within 2 m from the surface). The salts that accumulate in this water often become an important source of salts that moves upward into the root zone (Ayers and Westcot, 1985). A hydrological study of aquifers conducted across the study area in 2009 revealed that the nearest water table was at least 15 m deep. This would thus preclude the role of capillary rise as a major source of surface accumulation of salt in the surface soil of the fields.

A possible explanation for the high salinity in the top soil could be that the amount of irrigation water applied by the irrigation methods was not sufficient enough move, or leach, the salts downwards. Although natural rainfall could leach the salts, it is unevenly distributed over the crop growing season (Maraka, 1987). The high evaporation and transpiration rates in the area tend to decrease the limited amount of water available for leaching and transporting salts. Thus, the salt removed by leaching could be less than the salt added from the applied water and thus leading to build up of salts in the surface soil. Although fertilizers could also contribute to

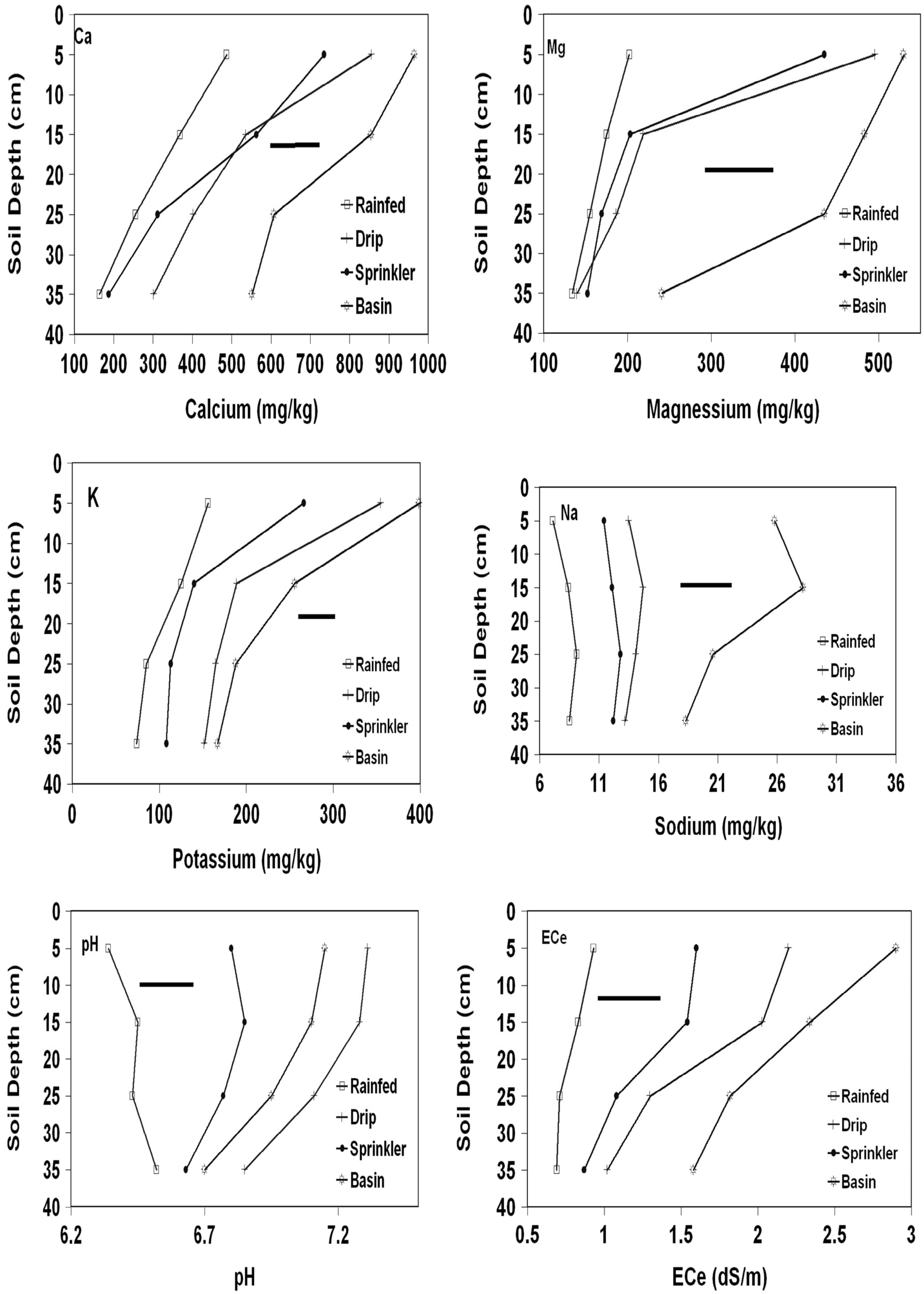

Figure 2. Distribution of soluble salts within the soil profiles of fields irrigated by different methods under urban agriculture in Mafikeng. Horizontal bars represent LSD ($P < 0.05$) between irrigation methods.

the accumulation of soluble salts in the soils, the irrigation water contains appreciable quantities of soluble salts which could constitute a major source of the soluble salts in the soils of the fields in the study. This call for an urgent need to improve the efficiency with which irrigation water is used by adopting irrigation scheduling that provides just sufficient water for the crop's different growth stages.

The distribution of salts in the profiles showed distinct differences among the irrigation methods and points to basin irrigation as the method that accumulated the highest amounts of soluble salts within the soil profiles. The lack of measurement of the exact volumes of water applied by the farmers makes it rather difficult to interpret the results, however, estimates of the applications showed that basin irrigation likely results in much more applied water (600 mm) than sprinkler (565 mm) or drip irrigation (585 mm), which would result in the most amount of salts applied during the 15 years of irrigation. Basin irrigation is widely used by farmers (23%) practicing urban agriculture in the study area, especially those producing fruits. The results of the study points to the need for the farmers to consider adopting alternative water management methods that avoid the accumulation of excessive salts in the root zone of the soils.

If the relative increase in the sodium levels in the soil is greater than the relative increase in soil ECe, the combination of the two could result in conditions that contribute towards reduction in soil hydraulic conductivity (Waldron et al., 1970). The presence of the sodium ion in irrigation water and/or in soil solution presents a potential hazard to soils and crops in that if the concentration continues to increase, it may be toxic to certain plants and may affect the soil structure (Frenkel et al., 1978; Rhoades et al., 1992). Claims have been made by some urban agriculture farmers of reduction in yields of up to forty-five percent due salinity by irrigation (City Council of Mafikeng, 1999). Rietz (2001) found that increasing salinity and/or sodicity in sugarcane plantations in Zimbabwe resulted in, not only a decline in yield, but also had detrimental effect on microbial activity and mineralization of soil organic C, N, S and P. Using the numerical values for salt tolerance ratings of agricultural crops given on Maas Hoffman tables (van Schilfgaarde and Skaggs, 1999), the crops currently grown by farmers in the study (maize, onions, carrots, spinach, peaches and vines) all have moderate levels of tolerance to salt and their productivity could be severely reduced if the salt buildup continues unabated. Thus, even if the current ECe in the soils does not exceed the threshold salinity of the crops that are grown, however, improvements in soil-water-crop management are needed to sustain irrigation in his semi-arid environment. The results of this study have shown that the irrigation methods are accumulating salts in the soil and that without such improvement, soil salinity will continue to increase until it reaches levels that are toxic to plants. In the long term, urban agriculture farmers may need to consider selecting crops/varieties that have a higher tolerance to water and soil salinity stress (Letey et al., 1985).

The results of this study suggest that if the irrigation continues as is, the potential for irrigation induced salinity risk is high and the sustainability of the already fragile soil resource may also be at risk. Guitjens et al. (1997) have shown that excessive salts within the root zone can be leached out of the root environment by applying more water than the estimated water consumption by plants and a method of drainage to carry the salts away. However, it would require large amounts of water, which is unavailable, to leach away the salts. This implies that more practical and affordable approaches need to be adopted.

There is therefore need to use irrigation methods and water management practices that will apply just a sufficient quantity of water to the root zone to meet the evaporative demand and minimize salt accumulation in the soil (Pereira, 1999). The use of mulch to minimize evaporation has also been shown to contribute to reduced salinization (Feng et al., 2005).

Conclusions

This study has highlighted the vulnerability of the irrigated soils used for urban agriculture to accumulation of salts after continuous irrigation for fifteen years. It is concluded that the irrigation methods are affecting the soil quality and points to the need for adopting improved and efficient irrigation management practices such as appropriate irrigation scheduling. Future studies should quantify the amount of salts contributed to the soil by different irrigation events and cropping seasons. Efforts need to be adopted that ameliorate the existing salinity and also prevent further accumulation of excess salts within the root zones. This may require periodic leaching of the accumulated salts to maintain acceptable levels of soil salinity in the root zone. Since it is well known that the tolerance of crop species/varieties to soil salinity is different, and that some crops can produce economical yields at much greater salinity levels than others, it is important that appropriate crop selection be exercised by farmers in the study area.

REFERENCES

ARC-IAE Agricultural Research Council-Institute for Agricultural Engineering. (1966). Irrigation design manual. Silverton, Pretoria.

Ayers RS, Westcot DW (1985). Water quality for agriculture. FAO Irrigation and Drainage Paper 29 (Rev I), FAO of the United Nations, Rome, Italy. 174pp.

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP (2008). Climate and Water. Technical paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, p. 210.

Cassel Sharmasarkar C, Sharmasrkar S, Miller SD, Vance GF, Zhang R (2001). Assessment of drip and flood irrigation on water and fertilizer use efficiencies for sugar beets. Agric. Water Manage., 46: 241-251.

Cetin O, Bilgel L (2002). Effects of different irrigation methods on shedding and yield of cotton. Agric. Water Manage., 54: 1-15.

City Council of Mafikeng (1999). Land Development Objectives (1998-2003). Vol. 1, Situation Analysis, City Council of Mafikeng, Mafikeng.

De Clercq WP, Van Meirvenne M, Fey MV (2009). Prediction of the soil-depth salinity-trend in a vineyard after sustained irrigation with saline water. Agric. Water Manage., 96: 395-404.

Department of Water Affairs and Forestry (DWAF) (1996). South African water quality guidelines, Vol. 4. Agricultural use: Irrigation. DWAF, Pretoria

DWAF (Department of Water Affairs and Forestry) (2002). National Water Resources Strategy: Summary. DWAF, Pretoria.

FAO-ISS-ISRIC (1998). World Reference Base for Soil Resources. World Soil Resource Report 84. FAO. Rome.

Feng ZZ, Wang XK, Feng ZW (2005). Soil N and salinity leaching after the autumn irrigation and its impact on groundwater in Hetao Irrigation District, China. Agric. Water Manage., 71: 131-143.

Frenkel H, Goertzen JO, Rhoades JD (1978). Effects of clay type and content, exchangeable sodium percentage, and electrolyte concentration on clay dispersion and soil hydraulic conductivity. Soil Sci. Soc. Am. J., 42: 32-39.

Gale J (1975). The combined effect of environmental factors and salinity on plant growth. pages 186-1992 In: Gale, J. (ed.). Plants in Saline Environments. Springer-Verlag, Berlin, Germany.

Ghassemi F, Jakeman AJ, Nix HA (1995). Salinization of land and water resources: Human causes, extent, management and case studies. University of New South Wales Press Ltd., Sydney, Australia.

Guitjens JC, Ayars JE, Grismer ME, Willardson LS (1997). Drainage design foe water quality management: Overview. J. Irrigation and Drainage Engineering. 123: 148-153.

Hassanli AM, Ahmadirad S, Beecham S (2010). Evaluation of the influence of irrigation methods and water quality on sugar beet yield and water use efficiency. Agric. Water Manage. 97: 357-362.

Hillel D (2000). Salinity management for sustainable irrigation: Integrating Science, Environment, and Economics. World Bank, Washington, DC.

Houk E, Frasier M, Schuck E (2006). The agricultural impacts of irrigation induced waterlogging and soil salinity in the Arkansas Basin. Agric. Water Manage. 85: 175-183.

Jones R, Marshall G (1992). Land salinisation, waterlogging and the agricultural benefits of a surface drainage scheme in Benerembah irrigation district. Rev. Market Agric. Econ. 60: 173-189.

Keremane GB, McKay J (2006). Successful wastewater reuse scheme and sustainable development: A case study in Australia. Water Environ. J., 21: 83-91.

Letey J, Dinar A, Knapp KC (1985). Crop-water production functions model for saline irrigation waters. Soil Sci. Soc. Am. J., 49: 1005-1009.

Lock K, Van Veenhuizen R (2001). Balancing the positive and negative health impacts. Urban Agric. Mag., 1(3): 1-5.

Maas EV, Grattan SR (1999). Crop yield as affected by salinity. In: Skaggs RW, van Schilfgaarde J (Eds.). Agricultural Drainage, Agronomy Monograph No. 38, Vol. 13-54, ASA, CSSA, SSSA, Madison, WI.

Malash N, Flowers TJ, Ragab R (2005). Effect of irrigation methods and water management practices using saline and non-saline water on tomato production. Agric. Water Manage., 78: 25-38.

Maraka N (1987). A contribution to the weather and meteorological studies of Bophuthatswana with special emphasis on the rainfall distribution and its applications to agro meteorological activities. Department of Transport, Meteorological Service, Mmabatho, South Africa.

Ould Ahmed, BA, Inoue M, Moritani S (2010). Effect of saline water irrigation and manure application on the available water content, soil salinity, and growth of wheat. Agric. Water Manage., 97: 165-170.

Pereira LS (1999). Higher performances through combined improvements in irrigation methods and scheduling: A discussion. Agric. Water Manage., 40: 153-169.

Perry C, Steduto P, Allen RG, Burt CM (2009). Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities. Agric. Water Manage., 96: 1517-1524.

Rhoades JD, Merrill SD (1976). Assessing the suitability of water for irrigation: theoretical and empirical approaches. FAO Soils Bull., 3: 69-109.

Rhoades JD, Kandiah A, Marshali AM (1992). The use of saline waters for crop production. FAO, 48, Rome, 133 p. htpp://www.fao.org/ag/agl/public.stm#aglwbu. Accessed on 13/09/2010

Rietz DN (2001). The effects of irrigation-induced soil salinity and sodicity on sugarcane yield and soil biological properties in the Zimbabwe lowveld. MSc Thesis, University of Natal, Pietermaritzburg.

SAS Institute Inc. (2006). SAS/STAT Users Guide. Vol. 4. Version 9, SAS Inst., Cary, NY.

Shalhevet J (1994). Using water of marginal quality for crop production: major issues. Agric. Water Manage. 25: 233-269.

Soil Classification Working Group (1991). Soil Classification: A Taxonomic System for South Africa. Memoirs of Agric. Natural Resources of South Africa, Pretoria.

South African Government (2001). White paper on spatial policy and land management. http://www.land.pwv.gov.za/White%20paper/whitetab.htm, Accessed on 25/08/2010.

Szabolcs I (1989). Salt Affected Soils. CRC Press Inc., Boca Raton, Florida, p. 274.

The Non-Affiliated Soil Analysis Working Committee (1990). Handbook of Standard Soil Testing Methods for Advisory Purposes. Soil Science Society of South Africa, Pretoria.

Van den Berg L, Van Veenhuizen R (2005). Multiple functions of urban agriculture. Urban Agric. Mag., 15: 1-3.

Van Schilfgaarde J, Skaggs RW (1999). Agricultural Drainage, ASA Monograph 38, American Society of Agronomy. Madison, WI, pp. 71-94.

Waldron LJ, McMurdi JL, Vomocil JA (1970). Hydraulic conductivity of an isotropically compressed soil. Soil Sci. Soc. Am. Proc., 34: 393-396.

Water Research Commission (1994). Surface Water Resources of South Africa Vol. II. WRC, Report No 298/2.1/4. Pretoria.