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SHORT RESEARCH COMMUNICATION

Matching soil salinization and cropping systems in communally managed irrigation schemes

Mphatso Malota[1] · **Joshua Mchenga**[1]

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Abstract
Occurrence of soil salinization in irrigation schemes can be a good indicator to introduce high salt tolerant crops in irrigation schemes. This study assessed the level of soil salinization in a communally managed 233 ha Nkhate irrigation scheme in the Lower Shire Valley region of Malawi. Soil samples were collected within the 0–0.4 m soil depth from eight randomly selected irrigation blocks. Irrigation water samples were also collected from five randomly selected locations along the Nkhate River which supplies irrigation water to the scheme. Salinity of both the soil and the irrigation water samples was determined using an electrical conductivity (EC) meter. Analysis of the results indicated that even for very low salinity tolerant crops ($EC_i < 2$ dS/m), the irrigation water was suitable for irrigation purposes. However, root-zone soil salinity profiles depicted that leaching of salts was not adequate and that the leaching requirement for the scheme needs to be relooked and always be adhered to during irrigation operation. The study concluded that the crop system at the scheme needs to be adjusted to match with prevailing soil and irrigation water salinity levels.

Keywords Drainage · Irrigation · Water management · Root-zone · Soil salinity

Introduction

Soil salinization is a gradual pre-desertification soil condition that reduces agricultural yields and lower the crop production potential of irrigated lands (White 1997). Agrarian history reports that as a result of salinization, between 2000 and 4000 BC, the Sumerians deserted their agricultural lands in the valleys of Euphrates and Tigris in the Mesopotamia (Luthin 1964; Pitman and Lauchli 2002). Prevailing world soil salinization statistics leans towards history to repeat itself. For example, Shrivastava and Kumar (2015) report that 33% of the world's irrigated lands are salinized and that the problem is increasing at the rate of 10% per year. At this rate, it is projected that 50% of total worlds irrigated land will be salinized by 2050 (Jamil et al. 2011). Africa and Asia account for 90% of the world's soil salinization problem (Wood 2008). Unfortunately, these two continents are also hardly hit by hunger and food insecurity (Armour and Viljoen 2008). Increasing crop production levels in these two continents will therefore require efforts that must aim at optimising crop yields from a unit irrigated land while at the same time increasing the irrigation water productivity.

According to Rowel (1994), FAO (2006) and Amezketa (2006), all irrigation water contains a certain level of salts, so that if not constantly flashed from the soil system, soil salinization becomes inevitable. The irrigation engineering community normally approaches the problem by adding a leaching requirement over and above the irrigation water requirement (FAO 2007). This means continuously recharging the groundwater table every time a farmer irrigates their crop. Thus with time, irrigation-induced soil salinization occurs gradually within the top soil layers, as leaching would no longer be achievable due to shallow water tables (Cetin and Kirda 2003). On the other hand, substantial research suggests installation of artificial subsurface drainage systems to solve the twin problem of shallow water tables and soil salinization (e.g. Jafari-Talukolaee et al. 2015; Bezborodova et al. 2010; Amezketa 2006; Christen and Skehan 2001). Unfortunately, subsurface drainage system installation costs have also increased, especially for farmers in developing countries (Darzi-Naftchali and Shahnazari 2014). It is therefore not strange that more than 70% of the total irrigated

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✉ Mphatso Malota
mphatsomalota@yahoo.com

[1] Department of Water Resources Management and Development, Faculty of Environmental Sciences, Mzuzu University, Luwinga, P/Bag 201, Mzuzu, Malawi

lands in the developing countries still rely on natural drainage to manage both the soil salinity and shallow water table problems (Benyamini et al. 2005).

In common with most developing countries experiencing high food insecurity levels, the Malawi government intensified its irrigation development plans especially in the Lower Shire Valley region where surface water resources are in abundance. All the developed irrigation systems in the region depend on natural drainage systems to manage both the salinity and water table problems. However, despite notable successes of the continued irrigation development in the region, information on the performance of these irrigation schemes, with more emphasis on preventing irrigation-induced soil salinization, is still not very clear. Reversing the effects of salinization can be very expensive; hence constant soil and irrigation water salinity monitoring is very important. Such analyses assist in diagnosing the soil salinization problem before the problem gets out of hand and taking steps to manage such problems. In addition, the information on changes of irrigation water and soil salinity level with time is necessary when recommending changes in the cropping system to match with both the irrigation water and soil salinity levels. This study was therefore conducted to assess the level of irrigation-induced soil salinization at a communally managed irrigation scheme in the Lower Shire Valley region of Malawi to recommend if there was a need to change or maintain the cropping system at the scheme.

Materials and methods

Study site description

The study was conducted at Nkhate irrigation scheme, located in Chikwawa district in the Southern region of Malawi. The net irrigable area of the scheme is 233 ha, divided into 22 blocks of various sizes. The scheme benefits a total of 1032 farmers. The scheme was first constructed with funding from the Chinese Government between 1979 and 1980 and was later rehabilitated under the Irrigation, Rural Livelihood Agriculture Development Project (IRLADP) in 2009. The type of irrigation adopted at the scheme is the gravity fed furrow irrigation whose irrigation water is diverted from Nkhate River which empties into the Shire River. Most of the major crops grown at the scheme are maize, beans and rice. The dominant soil types found at the scheme are sandy-clay and heavy clay soils.

Soil and water salinity measurement

Soil samples were collected across the soil profile from eight randomly selected irrigation blocks. To avoid bias in selecting the blocks, random numbers were first assigned to all the 22 blocks, out of which, eight blocks were randomly selected. This translated into 36% of total number of sampled irrigation blocks. Soil samples were collected at 0, 5, 10, 20, 30 and 40 cm depths from the soil surface, which constituted a soil depth occupying nearly 60% of most arable crop roots (Hurst et al. 2004). The soil samples were collected in the dry season when crops were produced solely through irrigation. This was in line with FAO (1999) recommendation that soil salinity determination should be conducted during the irrigation season to account for salts brought by the irrigation water. The soil samples were analysed for salinity (EC_e) in dS/m under laboratory conditions. The procedure followed in the analysis mirrored the one outlined by Warrick (2002).

Irrigation scheme operation

The study interviewed 50% of farmers cultivating in each of the targeted eight irrigation plots. On the other hand, information on irrigation scheduling, maintenance and details of the irrigation system design were obtained from the farmers and irrigation personnel in the area. Field observations on any signs of water ponding and waterlogging were made. Further to that, seasonal water table fluctuation (May to September 2016) in hand dug wells at the scheme.

Results

Irrigation water salinity and spatial variation of soil salinity

Results of irrigation water salinity variation measured at various locations where irrigation water samples were collected are presented in Fig. 1. The measured EC_{iw} at all the locations fluctuated between 2.1 and 2.3 dS/m with the minimum and maximum EC_{iw} measured at locations C and B, respectively. The mean EC_{iw} of 2.14 dS/m was obtained with a very small standard deviation of 0.10.

Table 1 presents a summary of descriptive statistics of soil salinity level measured at various soil depths in the

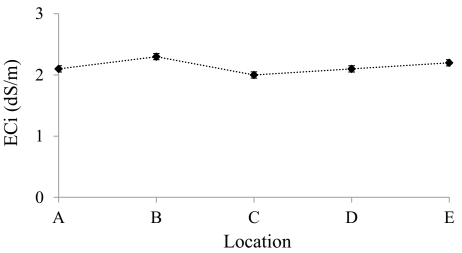

Fig. 1 Variation of irrigation water salinity measured at different locations at the site

Table 1 A summary EC_e (dS/m) variation in the eight irrigation blocks

Block	Maximum	Minimum	Mean	Std dev	CV (%)
A	3.5	1.7	2.4	0.6	27.7
B	3.1	1.5	2.2	0.7	31.7
C	3.3	1.1	2.4	0.9	40.8
D	3.6	2.1	3.0	0.5	18.3
J	3.1	0.8	1.9	0.8	46.0
P	4.2	1.8	3.0	0.9	30.5
N	6.4	2.2	3.9	1.5	38.4
W	7.8	4.3	5.9	1.4	23.7

Table 2 A summary of descriptive statistics of mean soil salinity (EC_e) variation at various soil depths

Soil depth (cm)	Max	Min	Mean	Std dev	CV (%)
0	7.8	1.5	3.9	2.1	53.8
5	7.4	1.7	3.6	1.8	52.5
10	5.7	1.6	3.1	1.2	38.7
20	5.7	1.7	3.1	1.2	38.7
30	4.7	1.1	2.6	1.1	44.6
40	4.3	0.8	2.4	1.2	50.0

eight irrigation blocks. The highest EC_e value of 7.8 dS/m was obtained in irrigation block W, while the lowest EC_e was obtained in block J. Similarly, the highest mean EC_e value also coincided with block W and lowest mean EC_e value coincided with block J. The EC_e levels varied highly within the 0–0.4 cm soil depth in blocks C, J and N with CVs of > 35%. On the other hand, blocks A, B, D, P and W registered a less variation of soil salinity across the soil profile (CV < 35%).

Soil salinity profiles

A summary of the basic statistics of soil salinity variation with respect to soil depth is presented in Table 2. Generally, mean EC_e values showed a decreasing trend with an increase in soil depth from 7.8 dS/m at the soil surface to 4.3 dS/m at 0.4 m soil depth. A CV of > 35% depicted a high variation of EC_e at all measured soil depths. Comparing levels of EC_e variation across the soil profile shows that EC_e varied more at the soil surface than any other soil depth. The level of EC_e variation showed an increasing trend from 53% at the soil surface to a CV of 38.7% at 0.20 m soil depth. Conversely, the EC_e variation trend increased again from CV = 44.6% at 0.30 m soil depth to a CV = 50% at 0.40 m soil depth.

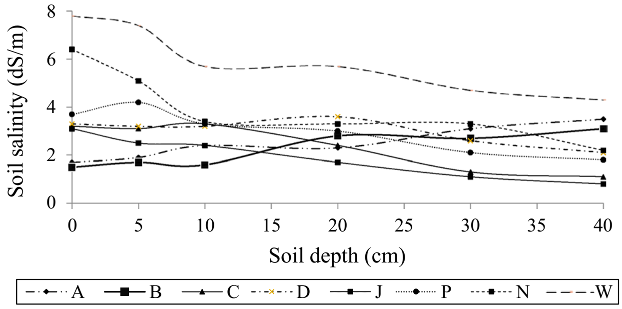

Fig. 2 Soil salinity variation at different soil depths in each of the eight irrigation blocks

Table 3 Yield potentials (%) of selected crops as influenced by mean EC_e (dS/m) (Tanji and Kielen 2002)

Crop	100%	90%	75%	50%	0%
Beans	1.0	1.5	2.3	3.6	6.3
Sweet potatoes	2.4	3.8	6	11	–
Maize	3.4	5.9	10	19	–

Root-zone soil salinity profiles

Results of soil salinity profiles (EC_e) within the 0–0.40 m soil depth are presented in Fig. 2. With the exception of EC_e profiles in blocks A and B, the rest of the EC_e profiles decreased with an increase in soil depth. Comparing the results to yield potentials presented in Table 3 clearly indicates that it would not be economical to grow beans in Block W, as its observed mean EC_e of 5.9 dS/m was very close to an EC_e of 6.3 dS/m, which would register a zero bean yield. On the other hand, with the exception of block W, out of the three crop types, maize, beans and sweet potato, maize would be the only viable crop to be cultivated in the rest of the irrigation blocks, as it would still yield 90% of optimal maize crop yield even with a mean EC_e of 5.9 dS/m.

Discussion

Irrigation water and soil salinity profiles

With respect to irrigation water salinity at the irrigation scheme, based on the Tanji and Kielen (2002) general irrigation water quality guidelines, the average EC_{iw} of 2.1 dS/m depicted that the salinity of irrigation water at the site was within the acceptable 0.0–5.0 dS/m range. Continual use of this irrigation water must, however, be approached with caution as soil salinization is a gradual process. Comparing the irrigation water salinity of 2.1 dS/m (i.e., 2100 µs/cm) obtained in this study to the ground water salinity of 35,000–36,000 µs/cm in the same area, as reported by Monjerezi et al. (2011), clearly depicted that the surface water sources in the area are more suitable for irrigation as opposed to use of ground water sources for the same irrigation purposes. The relatively good quality of surface waters in the region could explain why there is very little dependence on ground water sources for irrigation in the region.

In relation to the high ground water salinity levels in the region as reported by Monjerezi et al. (2011), the general deceasing trends of the soil salinity profiles in blocks C, D, J, P, N and W depicted no intrusion of salts into upper soil layers as a result of capillary rise from the ground water. This was further confirmed by the deep observed water table depths of ≥ 2 m at the three sites. The source of high salt accumulation in the upper soil layers in the aforementioned blocks could therefore not be attributed to the groundwater intrusion in the root-zone depth. Instead, the decreasing trends of soil salinity profiles could largely be attributed to the inadequacy of leaching of salts to deeper soil layers. On the contrary, the increasing soil salinity trends with soil depths particularly in blocks A and B, could be attributed to leaching of salts to deeper soil layers, though not adequate.

In comparison, the decreasing EC_e profiles corroborated very well with those reported by Chen et al. (2010) in the irrigated areas of Xinjiang in north-west China. In their study, Chen et al. (2010) reported EC_e values, which first showed a decreasing trend with soil depth in the first 0–40 cm. This was later followed by an increasing EC_e trend within the 45–87 cm soil depth. The authors attributed such a trend in the 0–40 cm soil depth to the use of saline water for irrigation. This according to the authors was exacerbated by inadequate subsurface drainage, and hence high soil salinity levels in the upper soil layers. On the contrary, in this study, the high EC_e values in upper soil layers are attributed to inadequate leaching which is supported by lack of water flow measurement structures at irrigation block entry points. This makes it difficult for the farmers to regulate irrigation inflows to their blocks to meet both the irrigation and leaching requirements.

Soil salinity spatial variation

The presence of both increasing and decreasing soil salinity profile trends at the irrigation scheme (Fig. 2) suggested that even in the same irrigation scheme, leaching of salts may vary spatially, both laterally and longitudinally. Assessment of the extent and severity of soil salinity in irrigated lands should therefore be treated as other soil factors with spatial variation characteristics, e.g., Carborn stocks (Dlamini et al. 2014). However, considering that reversing salinized soils is almost impractical especially in developing countries, timely and cost effective methods such as use of GIS and remote sensing to monitor soil salinity, while at the same time monitoring the spatial variation of soil salinity both in time and space may need to be explored, especially in irrigation schemes with intercropping systems. In the meantime possibility of planting moderate and high salt tolerant crops, e.g., maize, cotton and sorghum would be considered, particular in blocks W and N. However, a thorough market research for these crops should also be conducted before they can be fully adopted at the scheme.

Concluding remarks

In this study, the importance of assessing soil salinity in irrigation schemes and how such information is of critical importance in maintaining high crop yields has been clearly illustrated. Despite the irrigation water salinity at the site being characterised as suitable for irrigating most arable crops, adequate leaching of salts must also be provided to ensure low levels of soil salinity especially in the blocks that are dominated by heavy clay soils. The study concluded that that constant monitoring of soil and irrigation water salinity levels in irrigated lands is a good indicator to changing types of crops grown to match with crop salt tolerant levels and soil and water salinity levels.

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