Research article

Review on Causes, Effects, and Management of Soil Salinity on Irrigated Rice Fields in Tanzania

JIMMY FELIX MACHA
Graduate School of Agro-Environmental Science, Tokyo University of Agriculture, Japan

MACHITO MIHARA*
Faculty of Regional Environment Science, Tokyo University of Agriculture, Japan
Email: m-mihara@nodai.ac.jp

Received 22 May 2023 Accepted 2 August 2023 (*Corresponding Author)

Abstract Salinization is a process of increasing concentrations of salts in soil and water. Soil salinity is the most serious agricultural problem in irrigation agriculture in Tanzania. Severe salinity can cause significantly lower yields, food insecurity, and environmental degradation. If not properly addressed, soil salinization can accelerate and potentially expand to currently unaffected irrigated agricultural land. Despite the efforts made by the government and other stakeholders, rice production in irrigated rice fields in Tanzania is still experiencing low yields. Current rice yields are between 2.5 and 4 tons/ha, which is low compared to the average rice yields reported in other countries. Salinity problems are caused by the prevailing climate characterized by high evapotranspiration, geological and geographical characteristics of the area, quality of irrigation water, and inadequate land use practices. This paper aims to review available information on the causes and effects of soil salinity on irrigated rice fields in Tanzania and to provide information on management strategies to adjust soil salinity and improve soil fertility. References from books, papers, journals, online readings, and dissertation papers from different universities and institutions were used to get information for this paper review. In this review, the various reasons that cause soil salinity in irrigated fields in Tanzania have been identified, which are the nature of rocks, poor irrigation management, and non-compliance with established irrigation regulations. Also, the effects of soil salinity in Tanzania have resulted in a decrease in yields, an increase in costs of production, poor quality of products, and water shortages for irrigation. Lastly, some recommendations identified to solve the challenges of soil salinity include setting up a local drainage system on affected land, renovating some irrigation facilities, reclaiming the affected soil with gypsum and manure, and flushing all salt-affected water with non-salt water.

Keywords review, soil salinity, causes and effects, irrigated rice field, Tanzania,

INTRODUCTION

Globally, the challenge of soil salinity in areas that practice irrigation agriculture has been increasing day after day, resulting in crop production decreasing while also causing land environmental problems such as degradation, erosion, and siltation. Salinity affects about 800 million ha of arable lands worldwide and approximately 33 % of irrigated areas (about 74.25 million ha) are currently considered threatened by soil salinization by various degrees (Shrivastava and Kumar, 2015). According to Jamil et al. (2011), it's projected that by the year 2050, there will be more than 50 % of the farmland worldwide, which would become salt affected. Rice is the most sensitive cereal crop while barley is the most tolerant cereal crop (Munns and Tester, 2008; Karan et al., 2012). Salinity has serious effects on the percentage of filled spikelet, and grain weight, and can also hinder the uptake of essential nutrients in rice (Clermont-Dauphin et al., 2010). Most irrigation schemes, which are especially within arid and semiarid environments, are already experiencing increasing levels of salt-affected soil, solely due to the mismanagement of the soils, the use of poor-quality irrigation water, poor drainage systems, poorly designed and managed irrigation infrastructures, excessive use

of irrigation water and climate change (Kashenge-Killenga, 2010). Most irrigation water qualities have adverse effects on the physical properties of soil because it is mostly connected with the buildup of sodium ions on the soil exchange complex. The quality of water can impact the volatility of the soil aggregates which eventually leads to the dispersion of the clay particles and the clogging of soil pores. When underground water is made to move to the soil surface by evapotranspiration, the soluble salts condense on the soil particles on the surface and form a white crust.

Irrigation practices affect land by increasing the rates of leakage and groundwater recharge which results in the rise in the water table. The water tables when it rises bring salts into the plant root zone which affects both plant growth and soil structure; then the salt remains behind in the soil surface after the water has been taken up by plants or lost due to evaporation (Popay et al., 2009). Soil salinity is generally measured by electrical conductivity (EC) (Allison and Richards, 1954; Sonmez et al., 2008; Scudiero et al., 2017). A soil is considered saline if the EC of a saturation extract exceeds 4 dS m^{-1} at 25°C (Sonmez et al., 2008). Soil salinity or EC may be measured on the bulk soil (ECa), in the saturation paste extract (ECe), in soil: water ratio suspensions of 1:1 to 1:5 such as 1:1, 1:2, 1:2.5 and 1:5 or directly on soil water extracted from the soil in the field (ECw) (Allison and Richards, 1954; Sonmez et al., 2008; Kargas et al., 2018). Like other countries in Africa, soil salinity in Tanzania contributes to one of the most serious ecological and environmental problems in most of the irrigation schemes, so understanding the causes and effects of soil salinity in various irrigation schemes in Tanzania, will provide an opportunity for the government to come up with enabling policies to solve this challenge help farmers to practice irrigation agriculture that will specifically eliminate and reduce the problem of soil salinity in their respective areas. This is because among the factors that contribute to the increase in soil salinity are methods that are used by farmers in irrigation agriculture, like the use of fertilizers application and improper uses of irrigation facilities. The objective of this paper is to review the information on the causes and effects of soil salinity on irrigated fields and to come up with information on management strategies to control the problem.

OBJECTIVE

This review study tries to sum up and review available information on the causes and effects of soil salinity on irrigated rice fields in Tanzania. And it provides information on management strategies to adjust to deal with this challenge of soil salinity on rice irrigated fields in Tanzania to strengthen Irrigation Agriculture so that it can bring productivity and income to farmers in Tanzania.

METHODOLOGY

The methodology used to get information for this paper are references from papers, journals, online, and dissertation papers from different Universities and Institutions.

Causes of Soil Salinity on Rice Irrigated Fields in Tanzania

The main source of salt in arid and semi-arid areas includes rainfall (Rengasamy and Olsson, 1991), mineral weathering (Gunn and Richardson, 1979), irrigation and various surface water (Mehanni and Chalmers, 1986; Rengasamy and Olsson, 1993), groundwater which redistributes accumulated salts during evaporation, chemical applications (Rengasamy and Olsson, 1993) and man activities (Dregne, 1976). These sources, coupled with environmental modifications, lead to three different classes of salinization and sodicification that are grouped so for management purposes. These classes include Saline soils that have $EC_e > 4$ dS m^{-1} at 25° C and ESP < 15 (high soluble salts and low exchangeable Na^+). Sodic soils have $EC_e < 4$ dS m^{-1} and ESP > 15 (low soluble salts and high exchangeable Na^+). Saline-sodic soils are characterized by $EC_e > 4$ dS m^{-1} and ESP > 15 (both salts and exchangeable sodium are high), pH15%, and pH>8.5) (Allison and Richards, 1954). In Tanzania, some studies have been done to determine the sources of soil salinity in irrigation schemes,

those studies identify various reasons from different areas that do irrigation farming, and some of those reasons are as follows.

Table 1 Case papers used for gathering information used in this study

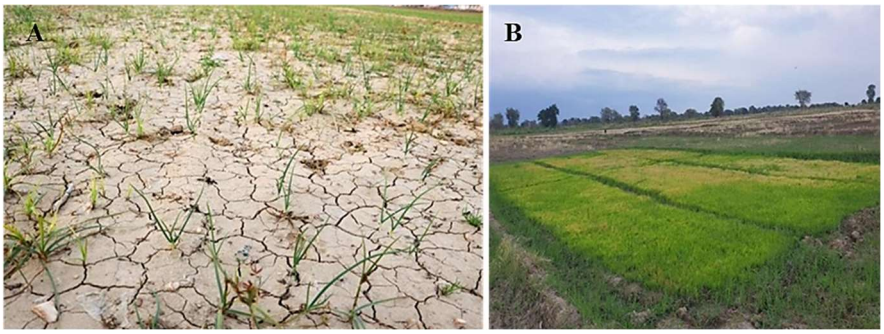
Researcher and year of publication	Research title	Journal name and published date	Causes of soil salinity	Effects of soil salinity	Management of soil salinity
Meliyo et al. (2017)	Evaluation of Salt Affected Soils for Rice (Oryza Sativa) Production in Ndungu Irrigation Scheme Same District, Tanzania	Sustainable Agriculture Research, 6 (526-2017-2656)	Nature location of the Irrigation area Poor Irrigation Management	Decrease in yields. Decrease in cultivation area.	Manure and limestone application The local drainage system infarms
Makoi et al. (2007)	Reclamation of sodic soils in northern Tanzania, using locally available organic and inorganic resources	African Journal of Biotechnology 6, no. 16.	Non-compliance Poor Irrigation Management	Increase in costs of productions	The local drainage system in farms Extension to farmers on irrigation management
Kashenge et al. (2012)	Soil characterization for salt problems in selected rice irrigation schemes	Journal of Advances in Developmental Research, 3(1).	Poor Irrigation Management	Water Shortages High costsof production	Application of drainagesystem Renovation facilities
Omar et al. (2022)	Exploring farmers' perception, knowledge, and management techniques of salt-affected soils to enhance rice production on small land holdings.in Tanzania	Cogent Food & Agriculture, 8(1), 2140470	Fertilizer application Poor drainage system	Decrease in yields. Decrease in cultivation Area.	Flashing salt water Extension services to farmers
Kashenge-Killenga et al. (2016)	Extent of Salt-Affected Soils and Their Effects in Irrigated and Lowland Rain-Fed Rice Growing Areas. of Southwestern Tanzania	Climate Change and Sustainability in Agriculture, 97-126	Poor Irrigation management	Increase incosts of production.	Proper Irrigation management

Firstly, the cause of soil salinity in irrigated fields in Tanzania is the natural location of an area, most schemes which are experienced soil salinity due to the nature of rocks in their respective areas, and this normally happens to the water source which is the source of water is from Spring or aquifer. Irrigation salinity occurs due to increased rates of leakage and groundwater recharge causing the water table to rise. Rising water tables can bring salts into the plant root zone which affects both plant growth and soil structure. This is common in an area surrounded by a mountain like in the Kilimanjaro region irrigation scheme as the Ndungu source of its irrigation water has salinity due to the nature of the rock (sedimentary rock) which causes the soil salinity.

According to Makoi, J. H. (2007), the strong reason for the soil salinity in areas where they are doing Irrigation Agriculture in Tanzania is poor irrigation management, which is often contributed to the farmers themselves not knowing the methods and principles of Irrigation Agriculture. This is muchly related to knowing when and how to irrigate (irrigation schedule), application of fertilizer, and poor drainage system which causes accumulation of water which in the end results in soil salinity irrigating with saline water adds salt to the soil and increases the need for applying more irrigation water to leach salts past the plant root zone.

Another source of soil salinity is non-compliance with various laws and guidelines set under the irrigation laws in the country, which states that before starting an irrigation scheme, the source of

water must be measured and tested to see if its water complies with the required quality for irrigation, including measuring the level of salt and consider the installation of salt control infrastructure as a drainage system in the scheme. Some people do not follow the guidelines set by the Irrigation Commission responsible for Irrigation Agriculture in the country.



Source: NIRC

Fig. 1 Soil affected by salt (A); yields of paddy affected by salt (B) at irrigation schemes in Tanzania due to poor irrigation management

Effects of Soil Salinity on Rice Irrigated Fields in Tanzania

Soil salinity is an environmental stress affecting agriculture globally, substantially reducing cultivated land area, crop productivity, and quality. Farmers can keep salinity problems in check by using fertilizer. It is widely recognized by soil scientists that soil salinity reduces crop yield. Salinity not only decreases the agricultural production of most crops, but also, affects soil physicochemical properties, and the ecological balance of the area. The impacts of salinity include—low agricultural productivity, low economic returns, and soil erosion (Hu and Schmidhalter, 2005). In Tanzania, soil salinity has caused various challenges, but the biggest one is the decrease in yields production, as statistics show that almost five percent (5%) of the area suitable for agriculture in many irrigation schemes in Tanzania is not cultivated due to soil salinity problem also there are some cases in some Irrigation scheme where they usually produce 3-4 t/ha now they are producing 1-1.5 t/ha due to problem of soil salinity (Luzi-Kihupi et al., 2015). Being not cultivated and abandoned automatically leads to a decrease in Production yields in a particular area and affects farmers' income incomes. Also, soil salinity, causes production costs to increase for farmers in Tanzania. as many of them use various methods to reduce salt, including using a lot of fertilizer so that their plants are healthy remaining, others also use gypsum to improve the soil structure damaged by salts. By doing all of this it leads to an increase in the cost of production (Kashenge, 2016). Another effect of soil salinity in Tanzania is irrigation water shortages, this is because in Tanzania most of the farmers reduce the salinity in their fields by applying much water to fields to flush out the water affected by salts and also to balance salt-affected soil, so a lot of water is used to flush out and by doing that it leads to shortages of water for irrigation on downstream. Water shortages downstream lead to conflicts among the farmers in most of the irrigation schemes in Tanzania (NIRC).

DISCUSSION

Management to Control Soil Salinity

There have been various efforts taken by farmers to control soil salinity in their irrigated fields to eliminate or reduce the problem, also governments, stakeholders, and research institutions are continuing to come up with a different approach to controlling soil salinity.

Provision of drainage system to the area affected, this method is mostly used by most farmers, they create local drainage systems on farms to remove water with salinity from the soil, and therefore the amount of soil salinity automatically is reduced and the drained water is removed through the

outlet. The other suggested ways of removing soil salinity recommended by researchers are such to renovate and close supervision of water inlet and outlet canals to prevent leakage of water between blocks, affected fields require reclamation by the use of gypsum, farm-yard manure, good drainage and flushing using good quality water, It is essential that drainage water, with its salt load from the affected soil, be removed from the scheme, the use of farmyard manure at a rate of 3 to 8 tons/ha is recommended to boost soil organic matter and improved soil infiltration to facilitate washing of salts to minimize the effect of salts (Meliyo, 2016). The farmyard manure will also supply some nutrients (N, P, and K) that were limiting in some soils and therefore need to be added to improve rice productivity andSoil reclamation will probably need to be a continuing practice in the most affected areas. The most economical solution to maintain productivity will probably be a combination of salt-tolerant variety selection and soil amelioration practices (Mdemu, M.L., 2020).

CONCLUSION

Controlling soil salinity, sustainable soil, and irrigation water management practices have a vital role in the production of rice at irrigation schemes in Tanzania country. Many approaches are available to rehabilitate salt-affected soils. These include physical methods (irrigation and drainage management); chemical amendments (gypsum, H_2SO_4, combined application gypsum with other organic amendments); and biological approaches (screening salt-tolerant genotype, growing ameliorating crop species, crop species in rotation, etc.). The agro-ecological conditions in Tanzania are comparable to many other countries where these approaches have successfully been tested. Therefore, there is a good potential for adopting these practices that will increase economic benefits to farmers.

ACKNOWLEDGEMENTS

First, I thank God for his blessing to me, special thanks to research fellows in the laboratory of Tokyo University of Agriculture for his supervision, mentorship, guidance, and advice. Lastly many thanks to JICA for the financial support of my research.

REFERENCES

Allison, L.E. and Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils (No. 60). Soil and Water Conservative Research Branch, Agricultural Research Service, US Department of Agriculture.

Clermont-Dauphin, C., Suwannang, N., Grünberger, O., Hammecker, C. and Maeght, J.L. 2010. The yield of rice under water and soil salinity risks in farmers' fields in northeast Thailand. Field Crops Research, 118 (3), 289-296, Retrieved from DOI https://doi.org/10.1016/j.fcr.2010.06.009

Dregne, H.E. 1976. Soils of arid regions. Elsevier Scientific Publishing.

Gunn, R.H. and Richardson, D.P. 1979. The nature and possible origins of soluble salts in deeply weathered landscapes of eastern Australia. Soil Research, 17 (2), 197-215.

Hu, Y. and Schmidhalter, U. 2005. Drought and salinity: a comparison of their effects on mineral nutrition of plants. Journal of Plant Nutrition and Soil Science, 168 (4), 541-549.

Jamil, A., Riaz, S., Ashraf, M. and Foolad, M.R. 2011. Gene expression profiling of plants under salt stress. Critical Reviews in Plant Sciences, 30 (5), 435-458, Retrieved from DOI https://doi.org/10.1080 /07352689.2011.605739

Karan, R., DeLeon, T., Biradar, H. and Subudhi, P. K. 2012. Salt stress induced variation in DNA methylation pattern and its influence on gene expression in contrasting rice genotypes. PloS one, 7 (6), e40203.

Kargas, G., Chatzigiakoumis, I., Kollias, A., Spiliotis, D., Massas, I. and Kerkides, P. 2018. Soil salinity assessment using saturated paste and mass soil: water 1:1 and 1:5 ratios extracts. Water, 10 (11), 1589.

Kashenge-Killenga, S. 2010. Breeding investigations for salt tolerance in rice incorporating characterisation of salt affected soils and farmers perceptions and preferences for tolerant cultivars in north-eastern Tanzania (Doctoral dissertation).

Kashenge-Killenga, S., Tongoona, P., Derera, J., Kanyeka, Z. and Meliyo, J. 2012. Soil characterization for salt problems in selected rice irrigation schemes, A key aspect towards the improvement of salt tolerance rice genotypes in North Eastern Tanzania. Journal of Advances in Developmental Research, 3 (1), 22-32.

Kashenge-Killenga, S., Meliyo, J., Urassa, G. and Kongo, V. 2016. Extent of salt-affected soils and their effects in irrigated and lowland rain-fed rice growing areas of Southwestern Tanzania. In Lal, R., Kraybill, D., Hansen, D., Singh, B., Mosogoya, T., Eik, L. (Eds.). Climate Change and Multi-Dimensional Sustainability in African Agriculture: Climate Change and Sustainability in Agriculture, Springer, 97-126.

Luzi-Kihupi, A., Kashenge-Killenga, S. and Bonsi, C. 2015. A review of maize, rice, tomato and banana research in Tanzania. Tanzania Journal of Agricultural Sciences, 14 (1).

Makoi, J.H. and Ndakidemi, P.A. 2007. Reclamation of sodic soils in Northern Tanzania, using locally available organic and inorganic resources. African Journal of Biotechnology, 6 (16), Retrieved from DOI https://doi.org/10.5897/AJB2007.000-2292

Mdemu, M., Kissoly, L., Bjornlund, H., Kimaro, E., Christen, E.W., van Rooyen, A. and Ramshaw, P. 2020. The role of soil water monitoring tools and agricultural innovation platforms in improving food security and income of farmers in smallholder irrigation schemes in Tanzania. International Journal of Water Resources Development, 36 (1), 148-170, Retrieved from DOI https://doi.org/10.1080/07900627.2020.1765746

Mehanni, A.H. and Chalmers, D.J. 1986. Effect of irrigation with saline water on soil properties and salinization of perennial pasture soils. Australian Journal of Experimental Agriculture, 26 (2), 173-179.

Meliyo, J.L., Kashenge-Killenga, S., Victor, K.M., Mfupe, B., Hiza, S., Kihupi, A.L., Boman, B.J. and Dick, W. 2017. Evaluation of salt-affected soils for rice (*Oryza sativa*) production in Ndungu irrigation scheme Same District, Tanzania. Sustainable Agriculture Research, 6 (1), 24-38, Retrieved from DOI https://doi.org/10.5539/sar.v6n1p24

Munns, R. and Tester, M. 2008. Mechanisms of salinity tolerance. Annual Review of Plant Biology, 59, 651-681.

National Irrigation Commission of Tanzania (NIRC). Retrieved from URL https://www.nirc.go.tz/

Omar, M.M., Shitindi, M.J., Massawe, B.J., Fue, K.G., Pedersen, O. and Meliyo, J.L. 2022. Exploring farmers' perception, knowledge, and management techniques of salt-affected soils to enhance rice production on small land holdings in Tanzania. Cogent Food and Agriculture, 8 (1), Retrieved from DOI https://doi.org/10.1080/23311932.2022.2140470

Popay, A. J., Tapper, B. A. and Podmore, C. 2009. Endophyte-infected meadow fescue and loline alkaloids affect Argentine stem weevil larvae. New Zealand Plant Protection, 62, 19-27.

Rengasamy, P. and Olsson, K. A. 1991. Sodicity and soil structure. Soil Research, 29 (6), 935-952.

Rengasamy, P. and Olsson, K. A. 1993. Irrigation and sodicity. Soil Research, 31 (6), 821-837.

Scudiero, E., Corwin, D.L., Anderson, R.G., Yemoto, K., Clary, W., Wang, Z. and Skaggs, T.H. 2017. Remote sensing is a viable tool for mapping soil salinity in agricultural lands. California Agriculture, 71 (4).

Shrivastava, P. and Kumar, R. 2015. Soil salinity, A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi Journal of Biological Sciences, 22 (2), 123-131.

Sonmez, S., Buyuktas, D., Okturen, F. and Citak, S. 2008. Assessment of different soil to water ratios (1: 1, 1: 2.5, 1: 5) in soil salinity studies. Geoderma, 144 (1-2), 361-369.

Zaman, M., Shahid, S.A. and Heng, L. 2018. Guideline for salinity assessment, mitigation, and adaptation using nuclear and related techniques. Springer Nature, 164.