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Evaluation of Salt Affected Soils for Rice (*Oryza Sativa*) Production in Ndungu Irrigation Scheme Same District, Tanzania

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Abstract

A study was carried out to examine distribution of salt affected soils by types and extent in the Ndungu Agricultural Development Project (NADP) area of Tanzania. The objective was to generate information to guide salt-affected soil management for sustainable rice production. Conventional methods including use of mini-pits and profile pits, coupled with farmers' experiences were used to characterise soil. A total of seven randomly selected soil profile pits located in major soils were dug and described. Soil was sampled from natural horizons for laboratory analysis. In addition a total of 158 topsoil (0 – 20 cm depth) composites soil samples were randomly collected from 90 sites of NADP project area for laboratory analysis. Results showed that a few blocks (block is a piece of farm of 6 to 12 acres) had high exchangeable sodium percentage and high levels of bicarbonates, indicating salt-affected soils. Soil pH, exchangeable sodium percentage (ESP), and electrical conductivity of soil paste extract (ECe) values as high as 9.06, 28.7 $cmol_{(+)}Na\ kg^{-1}$, and 14d Sm^{-1} were measured. Out of 90 blocks, 10 blocks (11%) showed slight to strong salt effects. Two blocks (2%) have been abandoned, and in some cultivated blocks zero yields were recorded due to salt content. The different levels of salinity development in the project area suggest site-specific remediation and appropriate management options be developed to improve crop production. These include rehabilitation of the irrigation infrastructure, use of farmyard manure as a soil amendment and growing salt-tolerant rice varieties. Furthermore, it is important to create awareness among farmers of the problem of salt-affected soil on rice productivity.

Key words: saline-sodic, high pH soils, salinity, sodicity, soil degradation

1. Introduction

Salt-affected soils, where salts concentrate on the soil surface causing severe decline of crop yields, are a worldwide problem (Metternicht & Zunk, 2003; Yadava et al., 2011; Shahid & Al-Shankiti, 2013). Such soils are found in diverse climates but they are dominant in arid and semi-arid climates (FAO, 2000; Graaff & Patterson, 2001; Robert & Ulery, 2011; Qadir et al., 2015). Global projections show that salt-affected soils are increasing. The extent of salt affected soils particularly in irrigated areas has increased in the last two decades from 45 million hectares to 62 million hectares between 1990 through 2013 (Ghassemi et al., 1995; Metternicht & Zinck, 2003; Qadir et al., 2014). These figures suggest that at global scale every day an area of about 2,000 ha of irrigated cropland is affected by varying levels of salinity (Qadir et al., 2014). The consequences of salinity and sodicity are harmful effects on plant growth and food production, reduction of water quality for uses other than agriculture, sedimentation and soil erosion. The consequences impact severely developing countries. According to Keshavarzi & Sarmadian (2012) soluble salts affect the productivity of soils by changing the osmotic potential of soil solution and by increasing the content of exchangeable sodium.

Salt-affected soils are categorized into three groups which are (i) saline soils characterized by high electrical conductivity of paste extract (ECe > 4 dSm^{-1}); (ii) sodic soils with higher exchangeable sodium percentage (ESP > 15%) but low ECe; and (iii) saline-sodic soils are a combination of saline and sodic soils characterized by high electrical conductivity (ECe) which is > 4 $dSm^{-1}$and ESP is > 15 % (Eynard et al., 2005). Criteria for assessment and categorization of salt affected soils into saline, sodic, and saline-sodic is usually done using the sodium adsorption ratio (SAR) and the exchangeable sodium percentage (ESP) (US Salinity Laboratory Staff, 1954; Charman & Murphy, 2007; Brady & Weil, 2008; Seilsepour et al., 2009) which are defined by equations 1 and 2:

$$\text{S.A.R.} = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}} \tag{1}$$

where:

S.A.R. = sodium adsorption ratio,

Na^+, Ca^{2+} and Mg^{2+} are concentrations of soluble cations $meqL^{-1}$

$$(\text{Exchangeable } Na^+/\text{CEC}) \times 100 \tag{2}$$

where:

ESP = exchangeable sodium percent, %.

Na^+ = measured exchangeable Na^+, meq/100g.

CEC = cation exchange capacity, meq/100g.

Literature shows that of the three salt affected soil categories, salinity is dominant (Rengasamy, 2006; Qureshi, et al., 2007; Thomas, 2010).

In Tanzania, salt-affected soils are a major constraint to production that contributes to low yields in most rice producing irrigation schemes (Kashenge-Killenga et al., 2012a; Makoi & Ndakidemi, 2007). Salt-affected soils are found in most semi-arid irrigated and non-irrigated, and even in lowland areas with high rainfall, which are characterised by high water tables (Kanyeka et al., 1995; FAO, 2001; Makoi & Ndakidemi, 2007).

Although there are a few scattered research reports on salt-affected soils in Tanzania (Mnkeni, 1996; Makoi & Ndakidemi, 2007; Kashenge_Killenga et al., 2012a), the extent of salt-affected soils in Tanzania is not well established. Mnkeni (1996) estimated that there were more than 2.9 million ha affected by salinity while 700 000 ha had high sodicity. On the other hand FAO (2000) estimated over 1.7 million ha are saline and 300,000 ha are sodic. Furthermore, FAO (2003) increased the estimated extent of salt affected soils to be over 3.5 million ha with proportions of 16% and 84% for sodicity and salinity, respectively. The disparity of these figures by FAO (2000, 2003) and Mnkeni (1996) suggest that the extent of salt-affected soils in the country is not well known. As a consequence, salt affected soils are not mentioned in research agendas and in policy formulation addressing agricultural problems in the nation. In reality, it is a serious problem that is turning agricultural land to barren, salty lands. In addition, several small rice irrigation schemes (classified as traditional irrigation schemes that are community managed) are experiencing reduced yields due to salt (salinity and sodicity) problems (Kashenge-Killenga et al., 2012b). Apart from the fact that the problem of salt-affected soils in rice production systems is increasing, information of type of salts and their extent is scanty or lacking (Kashenge-Killenga et al., 2012a).

Effective management of salt-affected soils requires correct diagnosis of the problem (Robbins & Gavalak, 1989; Eynard et al., 2005). Understanding the salinization processes and the limitations they cause to crop production is of significant importance for improvement of crop productivity with regards to constrains attributed to salinity and sodicity (Robbins & Gavalak, 1989). In the Ndungu Agricultural Development Project (NADP) area there is inadequate understanding of the prevailing salinization processes and the aerial extent affected and environmental factors attributed to salts build up the fact which limits the basis for recommendations for sustainable management options needed to mitigate the problem. This is the case also in most of the other existing irrigation schemes in Tanzania (Kashenge_Killenga et al., 2012a).

The NADP area that is located in Same District in the Kilimanjaro Region is among several projects launched by the Tanzanian Government, geared towards improving agricultural sector, particularly irrigated rice (*Oryza sativa*) production, which is the second staple after maize (*Zea mays*) to address food self-sufficiency and poverty reduction. The 680 ha NADP irrigation area was initiated in 1988, and it has developed into an important rice production area for the Kilimanjaro Region. However, yield reductions due to salt-affected soil is rapidly increasing to the extent that some farmers have had to quit severely affected soils because they were no longer productive (Kiangi, 2005). The genesis and fast spread of the sodicity and salinity problems may be accelerated by the prevailing climatic condition and geographical setting of the area which is characterised by high evapotranspiration that exceeds precipitation. However, information on distribution and identification of soil salt types and their extent in the NADP area is inadequate.

The objective of the study was to examine distribution and extent of salt-affected soils by their types in the NADP area so as to provide information that will guide development of salt affected soil management options. We hypothesize that a clear understanding of the distribution of salt affected soils by their types will enable the development of best management packages to help overcome the salinity and sodicity problems. Adoption of these practices should not only limit further development of salt problems, but also reverse the detrimental effects of salinity and result in sustained rice production in the NADP area.

2. Materials and Methods

2.1 Description of Survey Areas

NADP is located in the Same District, Kilimanjaro Region in the Pangani water catchment at the foot slope of South Pare Mountains. The alluvial/colluvial plain extends into Mkomazi Plain where the Mkomazi National Park is located. The geographic location is latitude -4^{0}22′0.34″ S and longitude 38^{0}4′28.06″ E, at an elevation of 510 m above seas level, and with a slope gradient ranging from 0.5 to 1%. Soil parent materials are mainly the neogene alluvium of diverse origin, forming mainly heavy clay soils that during dry season crack like Vertisols. Soils near river channels are Fluvisols. The Yongoma River that traverses the project area has been harnessed through a diversion and canal infrastructure for gravity irrigation.

Temperatures in the area are generally high during December-January with daily average temperatures over 30^{0}C, and lowest in July-August at 22^{0}C.Mean annual rainfall is 660 mm, most it falling during the rainy season. There are two rainfall seasons which are short and long rain-seasons which start on March through April and late October through December, respectively (Figure 1). Rainfall fluctuation and evapotranspiration influence the extent of the seasonal growing period (Figure 2). The unreliable, short rainfall locally known as ‘Vuli’ is used for crop cultivation. *Masika* (local name) for a long rainy season often is of short duration lasting for one month between March and April. This is a shorter period for most traditional crops grown for example a crop like maize (*Zea mays*) which stay in the field for 4 to 6 months. The shorter growing periods experienced in the NADP area has been a cause to frequent crop failures. The NADP area experiences long dry season, which starts from June through October.

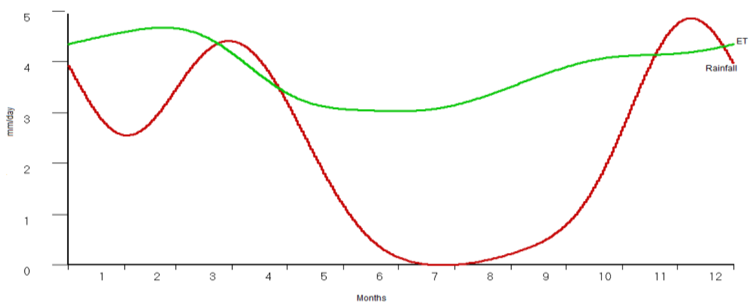


Figure1. Annual rainfall distribution in the NADP area, Same District, Tanzania

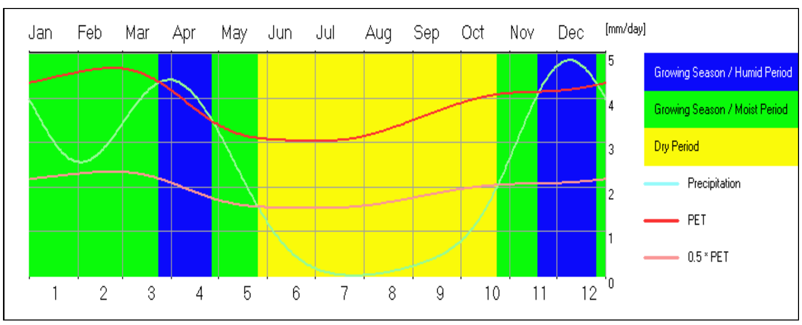


Figure 2. Dependable growing period for the NADP area, Same District, Tanzania

2.2 Soil Sampling

Fieldwork started by doing reconnaissance in the NADP area for familiarisation. Differences between soils were examined and delineated based upon digging of mini-pits (50 cm deep pits), profile pits, and farmers' experience. Auguring was not done because of soil hardness, attributed to both farm operations and soil properties (heavy clays). A total of seven soil profile pits randomly located in representative major soils were dug, described, and soil was sampled from natural horizons for laboratory analysis according to Soil Profile Description Guidelines by FAO (2006a). The soil samples were collected from natural soil profile horizons for laboratory analysis. Soil colours were named according to the Munsell Colour Notation (Munsell Colour Charts Inc., 1992). The scheme has 90 blocks of varied sizes in acres. Topsoil samples were collected from all 90 blocks, at a depth 0-20cm at randomly selected sites by a field team that included researchers, farmers, key informants, and NADP farm staff. Typically, soil composites was done by collecting 8 sub-samples randomly from three plots within a single block, mixed well, and by quarterly, it was reduced to 1 kg that formed a composite representing a block for laboratory analysis. A total of 158 composite soil samples were collected for laboratory analysis.

2.3 Laboratory Analysis

Soil pH was measured potentiometrically in water and in 1M KCl at the ratio of 1:2.5 soil-water and soil-KCl, respectively. ECe was determined using a paste extract where the leachate was used to take readings with an EC meter (Moberg, 2000). Organic carbon (SOC) was determined by the wet digestion method of Walkley and Black (Nelson & Sommers, 1982). Total nitrogen was determined by the Kjeldahl method (Bremner & Mulvaney, 1982). Phosphorus was extracted by the Bray and Kurtz-1 method and determined spectrophotometrically (Olsen & Sommers, 1982). The cations exchange capacity (CEC) and exchangeable bases were extracted by saturating soils with neutral 1M NH4OAc (Thomas, 1982) and the adsorbed $NH4^+$ was displaced by K^+ using 1M KCl and then determined by Kjeldahl distillation method for the estimation of CEC of soil. The bases Ca^{2+}, Mg^{2+}, K^+ and Na^+ displaced by $NH4^+$ were measured by atomic absorption spectrophotometry. Soil texture was determined by the pipette method after dispersing soil with sodium hexametaphosphate (Klute, 1986).

2.4 Data Analysis and Soil Classification

Assessment of soil soluble salts was done by measuring electrical conductivity and by calculating the sodium adsorption ratio (SAR) and the exchangeable sodium percentage (ESP) (Graaff & Patterson, 2001; Brady & Weil, 2008; Seilsepour et al., 2009). These were rated using established thresholds (FAO, 1999a&b). Descriptive statistics were used to derive tables and graphs depicting patterns of studied parameters and the results were used to compare severity of soil salt between different locations (soil profiles) in different blocks in the NADP area. Using both field and laboratory data the identified soil types were classified up to level-2 soil unit names according to the World References Base for soil resources 2014 (FAO, 2015).

3. Results and Discussion

3.1 Soil Texture

Figure 3 and Table 1 present particle size distribution of soils collected from the NADP area, indicating that texture is dominated by clay. Figure 3 shows individual textural separates with depth whereby sand, clay and silt particles are significantly different ($P<= 0.05$) in the upper part of the profile, but not significantly different for sand and clay in the subsoil (>100 cm from the surface). The subsoils are sandier that might negatively influence both the amount of water that can be stored and the crop vigour that is typically poor in sandy soils. This situation was observed randomly distributed in the NADP area, but generally the detrimental effects were not evident because sands are buried in the sub-surface layers (Figure 3). Some of these sandier spots noted to have poor crop stands were in the old riverbed, which had changed its course in past history. Other areas were affected by land levelling during the establishment of the scheme. Table 1 shows a tendency of clay declining with depth in some blocks, as indicated with a minimum value of 36% in topsoils but declines to 6% and 18% respectively, in subsoils (20-60cm and 60-200cm).

Soil texture is an important soil characteristic, particularly for irrigation and rice production. It influences water holding capacity, rootability, and retention of plant nutrients in soils (Hillel, 1982). In the NADP area, texture variability actually influences land use and field operations like tillage, and watering regime. The sites within the NADP area with sandy clay and sandy clay loam soils are used for maize growing during the dry season while areas with heavy clay soils are rarely used due to poor workability and poor drainage.

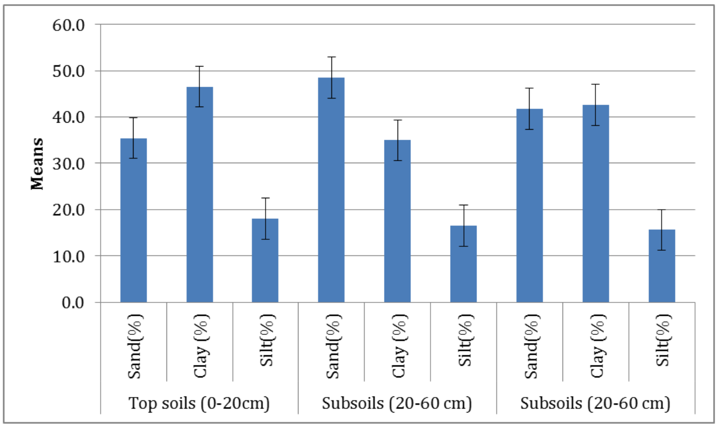


Figure 3. Distribution of soil particle size with depth, in soils from farms in the NADP area, in Same district, Tanzania

Table 1. Soil particle size distribution of the NADP area, Same District, Tanzania

	Top soils (0-20cm)			Subsoils (20-60 cm)			Subsoils (20-60 cm)		
Statistic	Sand (%)	Clay (%)	Silt (%)	Sand (%)	Clay (%)	Silt (%)	Sand (%)	Clay (%)	Silt (%)
Mean	35.4	46.6	18.0	48.5	35.0	16.5	41.8	42.6	15.6
SE	4.1	4.8	2.0	10.2	11.8	3.3	5.1	4.8	1.7
Median	40.0	40.0	14.0	47.0	35.0	16.0	39.0	41.0	16.0
SD	10.8	12.7	5.3	20.5	23.7	6.6	16.1	15.1	5.4
Range	28.0	30.0	12.0	48.0	58.0	14.0	56.0	50.0	18.0
Minimum	20.0	36.0	14.0	26.0	6.0	10.0	20.0	18.0	6.0
Maximum	48.0	66.0	26.0	74.0	64.0	24.0	76.0	68.0	24.0
n	158	158	158	158	158	158	158	158	158

3.2 Chemical Properties

3.2.1 Soil Reaction

Table 2 and Figure 4 present a summary of chemical properties of soils collected from sites within the NADP area. Table 2 shows variations of parameters between blocks and within soils. Figure 4 shows results of soil reactions, a measure of hydrogen ion concentration in the soil suspension as the pH values (Moberg, 2000). The results of soil pH indicate that it is predominantly alkaline, with pH values ranging from mildly alkaline (pH value 7.5) to strongly alkaline (pH value 8.5). Results show that the median pH value is 7.45, which implies that over 50% of soils are mildly alkaline. However, the minimum and maximum pH values range from moderately acid to strongly alkaline, with pH values of 5.7 and 9.06, respectively (Hazelton & Murphy, 2007).

Some profiles show pH declining with depth, while others have a pH increase with depth (Figure 4). The observed results imply that pH values at sites within the NADP area varies between and within soils. This could be attributed to the high concentration of exchangeable sodium as well as variations in calcium and magnesium concentrations (Table 3). The high pH values may also be attributed to the presence of bicarbonates. Most plants, including rice, grow well in soils of pH between 6.5 and 7.5 (Baize, 1993; Brady & Weil, 2008). This suggests that some of the NADP area soils are slightly to severely limiting to crop nutrients, particularly phosphorus and most micronutrients.

As the soil pH increases, the solubility of many nutrients is reduced because the nutrients are precipitated to solid materials that plants cannot use (Fernandez & Hoeft, 2009). It has been observed, for example, that the solubility of iron at pH 4.0 is 100 mgFe/kg soil but when the pH is increased to 6.0, the solubility drops to 0.01 mgFe/kg soil. At pH values above 7.5, the amount of iron in solution is often too low to sustain healthy plant growth. Furthermore, at high soil pH values, phosphorus, manganese, zinc, copper and boron also become minimally soluble, hence deficient. Many alkaline soils also contain low amounts of magnesium (Marschner, 2011; Fernandez & Hoeft, 2009). Thus, close to 50% of Ndungu soils in the NADP area may be experiencing macro and micronutrient deficiencies as influenced by high soil pH.

3.2.2 Soil Organic and Total Nitrogen

Table 3 and Figure 5 show results of both soil organic carbon (SOC) and total nitrogen percent in NADP soils.

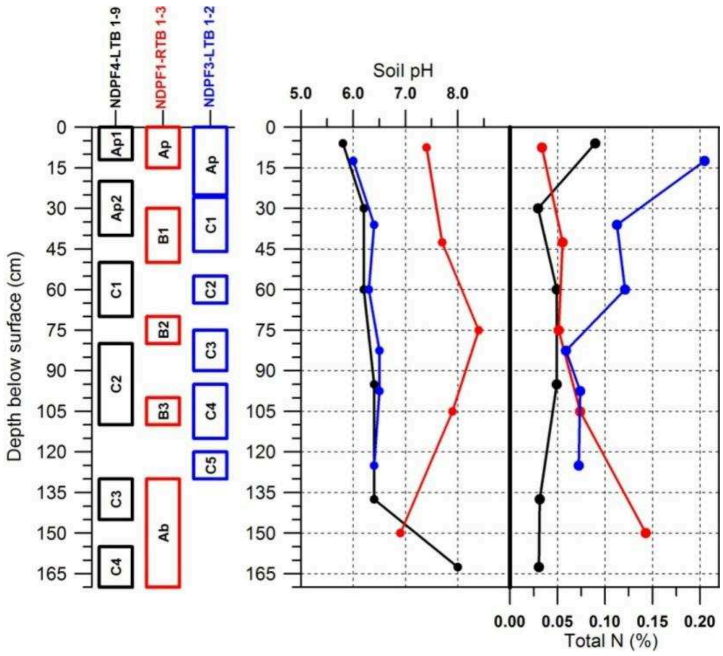
According to Landon (1991) and Baize (1993), the mean and median values for organic carbon are rated as medium (> 1.26 %). More than 50% of the NADP soils had organic carbon levels in the medium level (Table 2), that is an amount common for tropical soils (Landon, 1991). However, exceptionally low soil organic carbon levels were recorded for sites LTB2 and RTB1. This means that some NADP soils had soil organic carbon concentrations that would be considered minimum for sustainable crop production. Some research works have indicated that most of the productive agricultural soils have organic matter levels between 3% and 6% (Fenton, Alber, & Ketterings, 2008). The variability of soil organic carbon levels in the NADP area is attributed to farming practices which in the NADP area involves grazing and residual removal by burning. Turnover of soil organic carbon which is converted to soil organic matter by multiplying by a factor 1.72 depends on composition of the organic matter and cropping system, its use and tillage methods (Szajdak, Jezierski & Cabrera, 2003; Helfrich, Ludwig, Buurman & Flessa, 2006). The organic carbon serves as a reserve for many essential nutrients, especially nitrogen. During the growing season, part of the SOC reserve is turned into mineral nitrogen through bacterial activity and made available to plants (Korsaeth, Henriksen, & Bakken, 2002).

Table 3 also presents result for total nitrogen describing, the mean, median, minimum and maximum values. The minimum value is rated to be very low (<0.1%), while the mean and maximum values are rated as low to medium (Landon, 1991; Baize, 1993). The low levels of total nitrogen observed in Table 3 could be attributed to the inherent soil properties and management practices prevailing in the irrigation scheme. Total nitrogen and available nitrogen in the soil are affected by such factor as soil texture, drainage, slope steepness, rainfall, temperature, soil aeration and salt content (electrical conductivity/EC) that in turn, affect the rate of N mineralization from organic matter decomposition, nitrogen cycling, and nitrogen losses through leaching, runoff, or denitrification (Korsaeth, Henriksen, & Bakken, 2002; Meysner, Szajdak & Ku, 2006). Although nitrogen is required N in largest amounts compared to all other macronutrients, it is also the most often deficient because of the dynamic nature of its cycle in the soil and many pathways of loss (Marschner, 2011; Brady & Weil, 2008). Nitrogen is an essential component of proteins such as chlorophyll, (the green pigment in leaves) responsible for the dark green colour of leaves, stem and is an essential constituent of all proteins hence responsible for vigorous growth, branching/tillering, leaf production, size enlargement and yield formation of plants (Roy, Fink, Blair & Tandon, 2006; Brady & Weil, 2008).

Table 2. Soil chemical properties of composites samples from 90 rice fields of NADP farm, Same District, Tanzania

Statistic	pH (extract)	ECe(dSm^{-1})	TN (%)	OC(%)	P(mg/ kg soil)	Na^+($cmo^1l_{(+)}$/ kg soil)	K^+($cmol_{(+)}$/ kg soil)	Mg^{2+} ($cmol_{(+)}$/ kg soil)	Ca^{2+} ($cmol_{(+)}$/kg soil)	CEC($cmol_{(+)}$/ kg soil)	BS(%)
Mean	7.45	1.04	0.14	1.68	5.09	1.42	0.66	5.85	11.46	26.77	70.85
SE	0.06	0.18	0.01	0.08	1.25	0.44	0.15	0.48	0.98	2.20	0.90
Median	7.60	0.60	0.13	1.59	2.01	0.63	0.29	4.82	8.57	20.32	71.82
St Dev	0.52	1.52	0.05	0.64	10.37	3.66	1.24	3.98	8.18	18.24	7.46
Variance	0.27	2.32	0.00	0.42	107.56	13.40	1.53	15.85	66.87	332.65	55.64
Kurtosis	1.65	17.12	1.79	-0.39	9.57	47.35	16.50	3.69	0.46	4.48	6.33
Skewness	-1.33	4.06	0.96	0.24	3.35	6.63	4.09	1.82	1.21	1.94	-1.51
Range	2.40	8.38	0.27	3.04	41.72	28.41	6.29	18.90	33.62	94.40	49.65
Minimum	5.70	0.25	0.03	0.27	1.56	0.25	0.08	1.41	1.78	7.52	35.22
Maximum	9.06	8.63	0.30	3.31	43.29	28.66	6.38	20.31	35.40	101.92	100.0
n	158	158	158	158	158	158	158	158	158	158	158
CI (95.0%)	0.13	0.37	0.01	0.15	2.49	0.88	0.30	0.96	1.96	4.38	1.79

[1] TN = Total nitrogen; OC = soil organic carbon; $cmol_{(+)}$ = centimol-charge; dSm^{-1}= decisiemen per metre; SE = Standard error; St Dev = Standard deviation; CI = Confidence interval



Key: Ap, B1, B2… and Ap1, Ap2…C4 are different profile horizons

Figure 4. Distribution and variation of soil pH and total nitrogen (%) between and within profiles in NADP farm, in Same District, Tanzania

Soils represented by the two of the selected profiles indicate that total nitrogen declines with soil depth (NDPF3 LTB1-2 and NDPF1-LTB 1-9) while in NDPF1 RTB1-3, soil nitrogen increases with soil depth (Figure. 4). Heavy clay cracking soils that is commonly observed in Vertisols soils, and that is represented by profile NDPF1 RTB1-3, had higher total nitrogen levels in subsoils as compared to the light sandy clay loam soil (Cambisols) represented by profile NDPF3 LTB1-2. The observed nitrogen levels could be explained that in heavy clay soils that crack, materials from topsoils composed of organic matter fall in wide cracks and get trapped. This material then decomposes and through microbial decomposition adds to the soil nitrogen in subsoils. However, soil nitrogen according to Brady & Weil (2008) is a dynamic plant nutrient, which in most cases needs replenishment, either as organic manure or as mineral fertilizer. In the NADP area, some sites had total nitrogen values that were generally considered very low, i.e. total soil nitrogen values ranged between 0.1% and 0.2% (Landon, 1991; Baize, 1993). Generally, the results imply that NADP soils require nitrogen fertilisers for sustained optimal rice production.

3.2.3 Available Phosphorus

The median value of 2.0 mg P/kg soil (Table 2) indicates that over 50% of NADP samples had very low levels of available phosphorus, well below the critical minimum value of <7 mg P/kg soil (Baize, 1993) where deficiency is usually observed. Phosphorus is important in plants because it plays a critical role in physiological and biochemical processes such as photosynthesis, respiration, N fixation, root development, maturation, flowering, fruiting, and seed production (Johnston & Steen, 2000). Phosphorus deficiency can restrain plant growth, delay maturity, and reduce crop yield. The P deficiency symptoms are expressed in the older leaves because of its poor immobility in the plants (Ketterings, Czymmek, Albrecht, & Barney, 2014). In the NADP area, exceptionally low P-values were observed throughout. The low available P levels can be attributed to high soil pH and presence of carbonates that precipitates P and render it unavailable for plant uptake (Johnston & Steen, 2000; Fernandez & Hoeft, 2009). These results imply that NADP area soils are mainly deficient in phosphorus, suggesting that application of P fertilisers is essential for sustained and optimal rice yield production.

3.2.4 Cations Exchange Capacity (CEC)

The CEC represents the total amount of negative charges available to attract positively charged ions (cations) in soil solution. Results (Table 2) show that CEC levels ranged from low (minimum value of 7.5 $cmol_{(+)}$/kg soil) to very high (maximum value of 101.9 $cmol_{(+)}$/kg soil). Over 50% of samples had CEC levels in the acceptable medium rate (Baize, 1993; Landon, 1991). These results also show that there is variation of CEC between soils. CEC was also studied in the profile pits from sites within the NADP area to establish CEC status with soil depth.

Profile NDPF1-RTB1-3 had very high CEC levels in the topsoil, particularly the first two natural horizons with clay contents of 66% and 64%, respectively (Figure 5). There was a clear relation between high CEC and clay content. As clay content declined with soil depth to 48%, there was a corresponding low CEC, regardless of an increase of soil organic carbon. Profile NDPF1-RTB1-3 was from soil disturbed during levelling and the original topsoil was buried. This could be the reason that the typical decline of soil organic carbon with depth was not observed. The CEC at many of the NADP area sites is mainly determined by the clay content of the soil. Although some profiles indicate irregular increases of organic carbon with depth, this also could be attributed to changes in soil characteristics attributed to levelling. The soil represented by Profile NDPF1_RTB1-3 exhibit the vertic characteristics because of high clay contents and they have wide and deep cracks whereby topsoil falls into cracks, resulting in a mixing of top and subsoils.

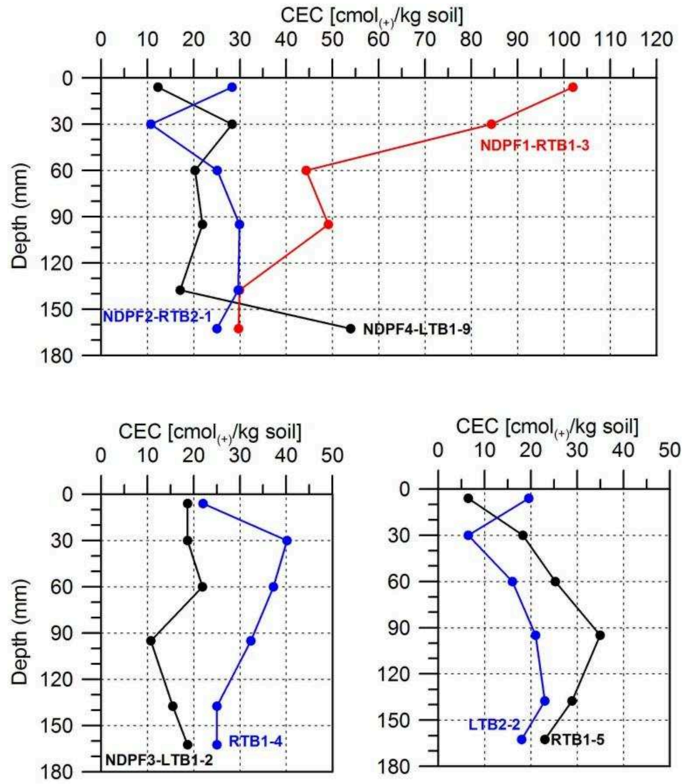


Figure 5. Variation of CEC between representative soil profiles and with depth at NADP area farms, Same District, Tanzania. The observed difference between NDPF1 RTB1-3 and the other two profiles may be attributed to levelling and soil texture

The CEC of NADP soils is dependent upon the amounts and types of clay minerals and organic matter present, as observed in NDPF1 RTB 1-3. Soils withhigh CEC were mainly characterised by high levels of clay content and organic carbon percentage. It is important to note that, although high CEC soils can hold more nutrients, a good soil management program is still required if these soils are to be sustanably productive over a long term period.

3.2.5 Exchangeable Bases (Ca^{2+}, Mg^{2+}, K^+ And Na^+)

Descriptive statistical results show wide variations between soils that can only be explained by different management of the various sites and the effects of land levelling when the project was being constructed. Exchangeable calcium levels in the NADP area soils are variable, ranging from medium (5-10 $cmol_{(+)}$/kg soil) to very high, with levels above 20 $cmol_{(+)}$Ca/kg soil (Table 2). Fifty of 90 studied sites had very high calcium levels according to the rating by Baize (1993), Landon (1991), and EUROCONSULT (1989) for tropical clayey soils. In addition, exchangeable calcium of < 2.0 $cmol_{(+)}$/kg soil was observed in some NADP sites.

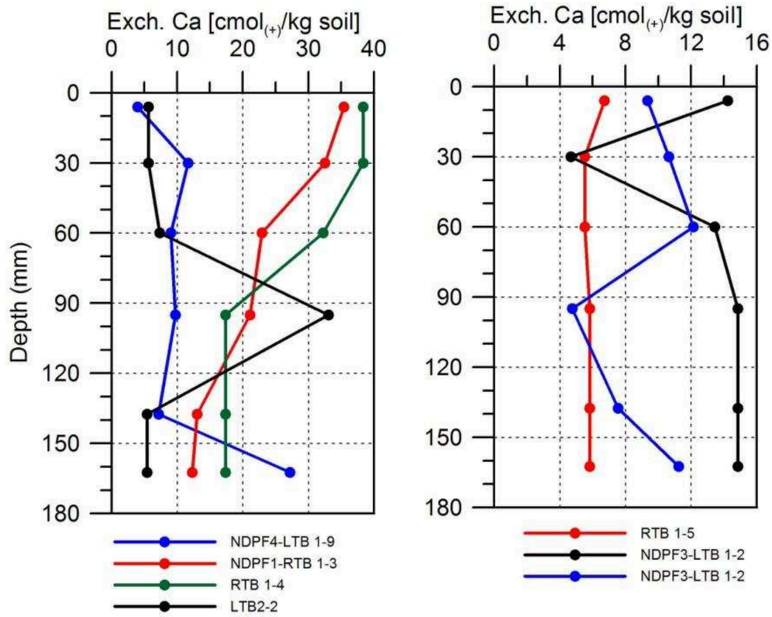


Figure 6. Distribution of calcium levels among selected soil profiles and with soil depth in studied NADP area farms, Same District, Tanzania

Profiles NDPF1 RTB-3 and RTB1-4 have excessively high levels of exchangeable calcium in topsoils but decline with soil depth (Figure 6). Profiles NDPF4-LTB1-9 and LTB2-2 show high calcium levels in the subsoils. The high levels are indicators of salt development. Magnesium in NADP soils had a median value of 4.8 $cmol_{(+)}$Mg/kg soil and over 50% of soils have high magnesium levels (Landon, 1991). There were variations, as indicated by minimum and maximum values of 1.41 and 20.3 $cmol_{(+)}$Mg/kg soil, rated to be medium to extremely high (Table 2) (Baize, 1993; Landon, 1991; EUROCONSULT, 1989) for tropical clayey soils. The high levels were localised in sub-soils at few sites represented by profile NDPF4 LTB1-9. These high Mg levels suggest the presence of localised salt-affected soils, which are present in some sites within the NADP area. In general the distribution of exchangeable magnesium between soils and with soil depth resembles that of calcium**.**

The minimum and median potassium levels in the composite soil samples were 0.08 and 0.29 $cmol_{(+)}$/kg soil, respectively. These levels are considered to be very low to low (Baize, 1993). However, there ware spots with extremely high values (6.4 $cmol_{(+)}$/kg soil)which are located in salt-affected sites. Representative profiles show large variations among soils (Figure 7).

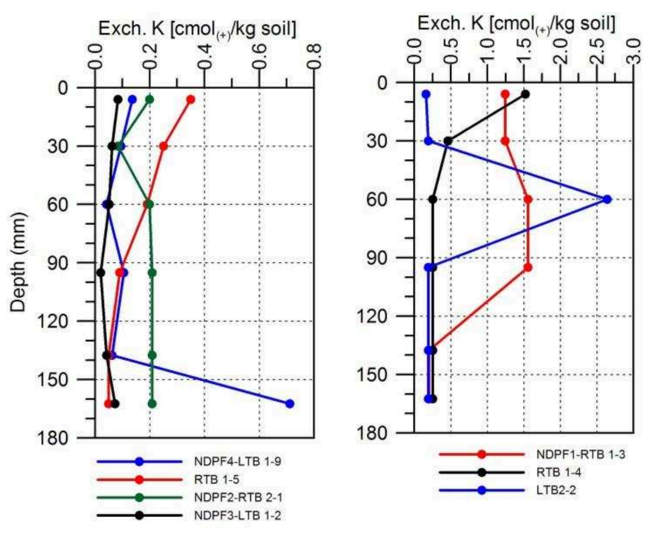


Figure 7. Distribution of exchangeable potassium among selected soil profiles and with soil depth in NADP farm, Same District, Tanzania

Composites soils samples show exchangeable sodium levels in NADP soils range from low to very high (0.25 to above 2 $cmol_{(+)}$Na/kg soil) (Table 2). The median exchangeable sodium value was 0.63 cmol(+)/kg soil, which is rated as medium (Landon, 1991; Baize, 1993). However, the maximum value of 28.7 $cmol_{(+)}$Na/kg soil was extremely high (Landon, 1991; Baize, 1993). High exchangeable Na levels were also observed in profilesNDPF4 LTB1-9 and RTB1-4,and these sodium levels were significantly higher in the subsoils. In contrast, NDPF1 RTB1-3 had high sodium levels in topsoils. These and other are salt affected spots in the NADP area need to be identified and managed properly before the fields become unproductive. These results on exchangeable bases at sites with high levels of Na, Mg, K and Ca coincide with areas where complaints of salt problems were put forth by farmers. These soluble salts accumulate and become concentrated to high levels, thus leading to salinity and/or sodicity problems

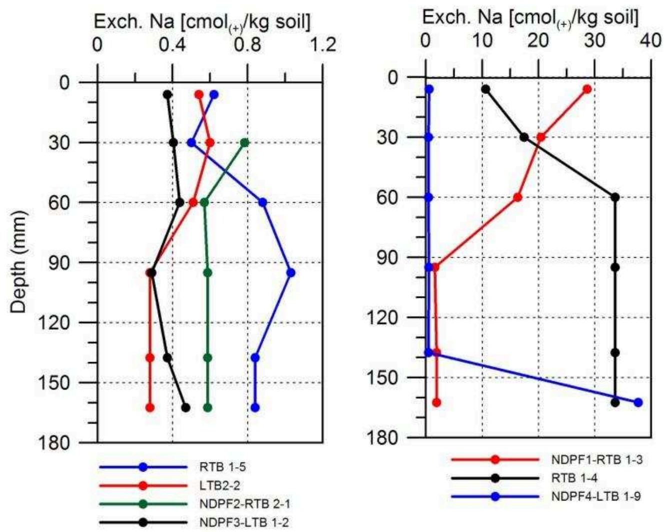


Figure 8. Distribution of exchangeable sodium between soil profiles and with soil depth in NADP farm, Same District, Tanzania

3.2.6 Base Saturation

The percent base saturation (BS) levels ranges from low with values of 20-30% to very high with values >80% (Table 2) (Hazelton & Murphy, 2007). The dominant soils in the NADP area farm have high BS as indicated by the median BS value of 71.8%. The percent BS refers to the proportion of the soil CEC occupied by the basic cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}). It is important to note that BS is influenced by the relative proportion of acid and basic cations. The acidic cations are H^{+} and Al^{3+}. The two types, basic and acidc derive their names from the way they influence the soils' pH. As the concentration of Ca^{2+} and Mg^{2+}ions increase, as is the case for most of the NADP area soils,and the number of H^{+} and Al^{3+}ions decrease. Base saturation is relatively high in moderately weathered soils formed from basic igneous rocks, such as the basalts. The pH of soil increases as BS increases, while in contrast, highly weathered and/or acidic soils tend to have low BS (Brady & Weil, 2008).The higher BS in NADP area farms may be reflecting high concentrations of bicarbonates and basic cations to hazardous levels, particularly sodium.

3.3 Salt Indicators in NADP Farm

Several sites (approximately10 representing 11% of affected areas), have high levels of exchangeable sodium, high exchangeable sodium percent (ESP), and high levels of bicarbonates (Tabl 3 and Figure 9). These are indicators of salt-affected soils, mostly saline-sodic, sodic, and saline in few blocks (Table 3). The cause of salts build-up in soils is due to changes in the local water balance, commonly brought about by mismanagement of irrigation and the lack of adequate drainage. The farm has irrigation supply canals but few drainage ditches. Therefore, irrigation water (which contains salts flushed from the soil) is not removed from the system. It may be re-used at downstream sites or may be allowed to evaporate in the field. This poor irrigation practice adds salts to the water table, which further exacerbates the problem by increasing subsurface salts. Rice (*Oryza sativa*) typically can only grow in soils with ECe of 3dSm^{-1} or less (Kashenge-Killenga et al., 2012b). It cannot grow well at the RTB1-3 and RTB1-4 sites, which have high ECe unless a salt-tolerant variety is used which a threshold of ECe not more than 9 dSm^{-1}. When the ECe value is above 3 dSm^{-1}, the plant fail to set seeds. If proper reclamation measures and good management practices are not put in place, rice growing will also fail in the LTB2-2 and LTB1-9 sites, which have very high ECe in subsoils (Table 3 and Figure 9).

Table 3.Soil salt indicators in the selected sites within the NADP area farm, Same District, Tanzania

Block	pH (H_2O)	ECe dSm^{-1}	Exch. Na^+	SAR	ESP	HCO^-_3 MgL^{-1}	Salt status
LTB2-1	8.03	1.71	4.85	1.43	29.22	54.9	Slightly saline
LTB2-2	5.68	0.51	0.83	0.26	7.36	-	Normal
LTB1-5	6.06	0.34	1.10	0.28	6.38	-	Normal
RTB2-1	6.85	0.12	0.48	0.12	2.77	79.3	Normal
RTB1-1	7.63	0.11	0.95	0.16	2.45	140.0	Normal
LTB 2-2	9.06	0.96	16.88	2.94	33.43	115.9	Sodic
RTB1-4	8.02	13.08	16.96	2.41	23.85	78.2	Saline-Sodic
RTB1-4	8.11	8.31	13.87	3.1	48.25	73.2	Saline-Sodic
RTB1-3	7.41	28.66	28.66	7.69	28.12	30.5	Saline-Sodic
RTB 1-5	5.8	0.14	0.62	0.40	9.57	-	Normal

Slightly = just at the start /beginning of salinity

Also, when exchangeable Na levels exceed 15% of the CEC, physical and chemical soil properties are negatively affected. Under these conditions, water and air infiltration into the soil may be reduced and poor growing conditions may result (Ondrasek, Rengel, & Veres, 2011). To overcome this problem, Ca^{2+} is added to replace the Na^+on the CEC sites (Horneck, Ellsworth, Hopkins, Sullivan & Stevens, 2007; Syers, Johnston & Curtin, 2008). Sodium in the soil water is then leached out of the rootzone by excess irrigation water or rainfall. The amount of Ca^{2+} needed to replace the Na^+ is based on the amount of exchangeable Na^+ as well as Na^+ saturation.

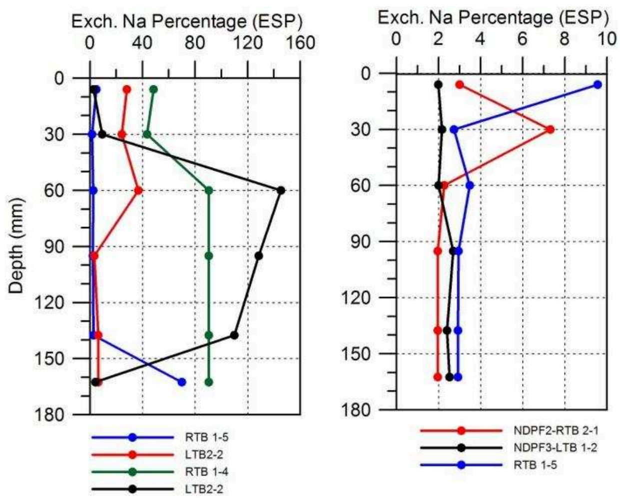


Figure 9. Distribution of exchangeable sodium percentage (ESP) among selected soil profiles in NADP area farms, Same District, Tanzania

The results of this work show that the NADP area definitely has a salinity problem that needs to be addressed before additional areas become unproductive and abandoned. Out of over 90 sites within the NADP area, 10 show slight to strong salt effects, representing 11% of the whole irrigation scheme. Similar effects have been reported on fields located outside the NADP area. Farmers have already abandoned the RTB 1-3 and RTB 1-4 sites. According to farmers, the value and yield of soils with high contents of salts are reduced to zero. This has caused severe socioeconomic problems, one being exodus of men to town and abandoning families. The low soil productivity has also prompted farmers to resort to clearing natural forests by illegal timbering and charcoal burning in order to support their families.

The symptoms of soil erosion are everywhere and some houses were being threatened by gully erosion. This phenomenon has been observed not only in Ndungu but also in the nearby villages. The consequences of low production and abandoned farmland in these areas are enormous, since farmers depend on the rice crop for both food and cash for their families. Salts accumulation in farms have been attributed primarily to poor irrigation water management. Other contributing factors include lack of maintenance and repairs of irrigation infrastructure, inadequate knowledge about salinity and its effects by farmers, water managers, government leaders, and inadequate resources to address the problem. The problem encountered in the NADP area has been reported as a serious problem worldwide. For example, it has been reported that the global cost of irrigation-induced salinity/sodicity is equivalent to an estimated US$11 billion per year (FAO, 2006b).

4. Conclusions and Recommendations

A study was carried out in the Ndungu Agricultural Development Project region to determine the causes of farmer's complaints concerning reduced rice yields, which in some locations were to the extent that some fields were abandoned. Yield losses will continue to occur if management practices and remediation measures are not taken to address the problem. Based on our study results, soils were classified as salt-affected when the pH values was > 7.5; the electrical conductivity (ECe) was > 3 dSm^{-1}, and exchangeable sodium percentage (ESP) was > 15%. The salt affected soils are categorised into three types: saline, sodic, and saline-sodic. The soils of the NADP region are mainly saline-sodic and, to a lesser extent, sodic. Salinity was also noted in few spots.

Social and ecological factors have contributed to the development of the salt affected soils. The parent material from which the soil in the area developed is rich with bases. This, combined with inadequate precipitation, resulted in limited leaching of bases during soil formation. The problem has been intensified through poor irrigation practices, a broken irrigation system (which increases seepage), as well the as lack of knowledge of the impact of salt-affected soils and their management on rice yields. In addition, soil fertility is quite variable between and within soils. Some of this can be attributed to levelling done during establishment of the project area, where cutting of topsoils in some places and filling in others was done. Other on-going soils and farm management practices such as grazing of animals, burning, and collection of grasses have contributed to soil organic matter decline and general soil degradation. As a result, the major nutrients are at very low to deficient levels in many of the salt-affected soils.

To minimize productivity losses due to salt accumulation, the use of soil and water best management practices are strongly recommended as follows:

1. Renovate and close supervision of water inlet and outlet canals to prevent leakage of water between blocks.
2. 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 scheme.
3. 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. 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.
4. Soil 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.

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