BREEDING INVESTIGATIONS FOR SALT TOLERANCE IN RICE INCORPORATING CHARACTERISATION OF SALT AFFECTED SOILS AND FARMERS PERCEPTIONS AND PREFFERENCES FOR TOLERANT CULTIVARS IN NORTH-EASTERN TANZANIA

By

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy (PhD) in Plant Breeding

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Thesis Abstract

Rice (*Oryza sativa* L.) is the principal crop of North Eastern Tanzania but production is threatened by salt affected soils, drought and the use of un-adapted cultivars, among other constraints. Little research and hardly any breeding have been done on the aspects of salt tolerance of the crop in sub Saharan Africa, leading to low yields and low production in rice irrigation schemes under arid and semi arid conditions. A project was therefore implemented in North Eastern Tanzania during 2007-2010 seasons to investigate the possible breeding contributions to enhance productivity and production of the crop in salt affected areas.

The objective of this study was to: a) determine farmers' perceptions on both salt problems and their effects on rice crop productivity as well as establishing farmers' needs and preferences for rice varieties in the targeted irrigated environment; b) determine the extent of salt problem in both soil and irrigation water in the available rice irrigation schemes in the North-eastern Tanzania; c) identify the major physiological mechanisms associated with salt tolerance in farmer-preferred native varieties and landraces; and d) determine the mode of inheritance of salt tolerance in rice.

Participatory rural appraisal was conducted in Mkomazi and Mombo villages in Tanga region with the aim of understanding characteristics of rice–based farm economy, farmers' perception of agriculture constraints and variety preferences in salt affected areas of North-eastern Tanzania. This was follwed by a preliminary study to understand soil characteristics in relation to salt problems and its extent in selected nine rice irrigation schemes. Studies was established under controlled conditions to assess the salt tolerance of some rice farmers preferred rice cultivar and evaluate the putative traits in the rice materials that contribute to the performance of a genotype under saline and saline-sodic condition. Thereafter, genetic mechanism governing various morpho-physiological parameters in selected Tanzania local farmers' preferred varieties and salt tolerant donors under saline and sodic soil conditions of North Eastern Tanzania were determined.

A participatory rural appraisal (PRA) established that rice was a major staple food and cash crop and rice farming was a major economic activity in the area. However, soil degradation through increased salt affected soils was identified as the major factor responsible for irrigated rice yield decline. Major varieties grown are salt sensitive, and salt tolerant varieties were not available. The study also revealed that most farmers' preferred traits of rice cultivars were high yield potential, aroma, early maturing, medium plant stature, tolerance to salt and drought. Improvement of these characters in new salt tolerant varieties would increase food production in fields with low or zero productivity and the well-being of the poor farmers.

A soil characterisation study indicated the magnitude of the problem, whereby, seven out of nine studied irrigation schemes were affected and sodic and saline-sodic conditions were the dominant types of soils. Poor irrigation canals and management of irrigation water were the driving factors that contributed to salts accumulation causing a decline in productivity.

Experiments were established under controlled environments to evaluate the tolerance of 10 and 11 rice genotypes under saline and saline-sodic stresses, respectively. Significant variation between genotype and significant interactions between genotype and salt treatment ($P<0.001$) were observed for all characters studied. Genotype Pokkalli, IR 67076-2B-21-2 and IR 56 showed superior performance under saline, whereas CSR 27, Nerica 2 and IR 56 had superior performance under saline-sodic. The study therefore established that, all the local farmer preferred cultivars except IR 56 performed poorly under both salt stress environments. High seedling vigour, less leaf injury, less Na^+ and high K^+ accumulation in leaves, low Na^+/K^+ ratio of ion uptake, high spikelet fertility, increased grains per panicle and 1000 grain weight were considered as the desirable characteristics therefore can be used in developing lines for salt tolerance for production under saline and saline - sodic conditions.

Gene action and combining ability studies for nine morpho-physiological traits were studied under normal, saline and sodic soil environments. The rice populations were generated through 7 x 7 full diallel crosses and advanced to F2. The parents comprised two donors for saline tolerance, one donor for sodic tolerance and four salt sensitive farmers preferred varieties. Both additive and non-additive gene effects were important in the inheritance of the characters studied in all soil environments. However, additive effects were more important for the number of tillers, shoot Na^+, Na^+/K^+ ratio and plant height. Both additive and non-additive gene effects were important for spikelet fertility, days to 50% flowering, number of grains per panicle, 1000 grain weight, and grain yield; however the magnitude of additive gene effect was higher than non additive effects. Amongst the parental lines, the best general combiners for yield along with other traits were TXD 306 and IR 67076-2B-21-2 under normal non-saline/sodic condition; IR 56, Pokalli and TXD 306 under saline condition and CSR 27 and TXD 306 under sodic conditions. The overall results from this study indicated the possibility of improving both yield and salt tolerance from this set of germplasm; therefore contributing to increasing rice yields in the marginal salt affected environments.

Declaration

I, Sophia Kashenge-Killenga, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
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Signed …………………………………………………….............

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As the candidate's supervisors, we agree to the submission of this thesis:

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Professor P. Tongoona (Supervisor)

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Dr. John Derera (Co-Supervisor)

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Dedication

My Father Shaban Selehe Kashenge and Mother Saada Mussa Munisi

My Husband Raymond Roman Fundi Killenga

My children Ron, Fern, Nike and Noby

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Introduction to Thesis

1. Significance of rice crop in Tanzania

Tanzania is the second largest rice producer and consumer in eastern, central and southern Africa (ECSA) after Madagascar (Kafiriti, 2004; FAO, 2004). Within the country, rice ranks second in production and consumption after maize (Kanyeka, 2001). About 60% of the population eats rice at per capita consumption of 23.27 kg (FAO, 2001; FAO, 2002). Annual per capita consumption rose from less than 15 kg in the 1970s to about 20 kg in 2004 (FAO, 2005). Furthermore, rice is also one of the strategic cereal crops for the country's food security, ranking third after maize (*Zea mays* L.) and cassava (*Manihot esculent*a Crantz) (Kanyeka *et al*., 1995). Therefore, adequate rice should be produced in Tanzania.

Kanyeka *et al.* (1995) and Msomba *et al.* (2002) reported that more than 90% of rice in the country is cultivated by smallholder peasant farmers on small holdings ranging between 0.25 - 2ha. Small-scale paddy farming is normally done in lowlands using traditional or improved small-scale irrigation facilities or rain-fed farming. However, there are a few large-scale and several small-scale paddy farms that use modern irrigation techniques. The large scale irrigation schemes are owned by private companies that were formerly state-owned. On the other hand, small-scale schemes are owned by government and run by farmers' communities. Generally rice production in these schemes is very low and, as a result, rice farmers continue to suffer from household food insecurity. Both biotic and abiotic stresses constrain yield (Msomba *et al.,* 2002; MAFS, 2008). The abiotic stresses include: drought, flush floods as well as adverse soils (Kafiriti, 2004; Msomba *et al.,* 2002). Adverse soils, particularly salt affected soils are very common in arid and semi arid irrigated environments and are less studied, therefore compromising farmers' yields in marginal environments (Tesfai *et al.,* 2002; Siyal *et al*., 2002; Chinnusamy *et al.,* 2005, Mishra *et al.,* 2006).

2. Prospects and effects of Salt Affected Soils (SASs) in developing countries

According to TWAS (2006) global population currently stands at six billion. By 2050, it is predicted to reach nine billion; this means three billion more mouths will need to be fed from a dwindling cultivable land mostly in developing countries. Adding to that, climatologists also predict that it is precisely these countries that will be most severely affected by a typical weather pattern, with drought likely to become more frequent and prolonged due to the effect of climate change increasing more salt affected areas (Cassman, 2004). Experts predict that by 2050, salt affected soil – salinity will affect some 50% of the world's arable land and more impact will be observed in Africa particularly in Sub Saharan countries (TWAS, 2006).

According to (Cassman, 2004) salt affected soils occur naturally in arid and semi-arid regions and as water development brings more land into irrigation, the problem expands. The condition is aggravated by poor soil drainage, improper irrigation methods, poor water quality, and insufficient water supply for adequate leaching and insufficient disposal sites for water that leaches salts from the soil. Salt accumulation in soils has a considerable contribution in an increase in adverse soils affecting crop productivity. The problems caused by salt soils are compounded when a high water-table impedes root development and concentrates salts in the already limited root zone.

According to Siyal *et al.* (2002) and Tesfai *et al.* (2002) currently, there is extensive SASs on all the continents, but their extent and distribution has not been studied in detail. Estimates are in general close to 1 billion hectares, which represents about 7% of the earth's continental extent. In addition to these naturally salt affected areas, about 77 million ha have become saline as a consequence of human activities, with 58% of these concentrated in irrigated areas. Unfortunately, irrigated agriculture is one of the major sectors seriously endangered or affected by salt affected soils (Alam, 2006; Flowers and Flowers, 2005; FAO, 2000). According to Szabolcs (1987), ten million ha of irrigated land are abandoned every year because of the adverse effects on soils resulted from mismanagement of irrigation principles. Farming practices have made a huge contribution to the increase of SASs at various levels in irrigated fields resulting in reduction of cultivable land (Cassman, 2004). Therefore, according to Tesfai *et al.* (2002 need exists for time to time evaluation of soil and irrigation water in these salt affected areas for proper management planning.

3. Rice production and constraints with emphasis on SASs stress

Generally, rice is grown in almost all regions of Tanzania but at various levels of importance. However, yields are low and still dwindling compared to the increasing consumption (Kafiriti, 2004). Due to increasing demand for rice consumption, about 10 to 25 % of the total consumption is imported annually to augment the shortfall (Kafiriti, 2004; FAO, 2005). According to Peng *et al*. (1999), rice grown on the most productive irrigated land has achieved nearly maximum production with current cultivars. Environmental degradation including increase in adverse soils, pollution, and night time temperature elevation due to global warming results in increased production constraints (Cassman, 2004). The mean yields in smallholder farms are, however, very far below the potential (Fashola *et al.,* 2007).

In Tanzania, low yields ranging from 0.5 to 2.0 t ha^{-1} and from 4.5 and 6.0 t ha^{-1} have been reported from farmers' fields and in some irrigated rice projects, respectively (Kafiriti, 2004; Msomba *et al.,* 2002), while the potential yield of modern rice varieties is 10 to 11 tha^{-1} under tropical humid conditions (Fashola *et al.,* 2007). Low yields in farmers fields are attributed to many factors including the use of traditional low yielding varieties, poor soil fertility, low or non use of fertilizers, weed infestation, pest and diseases (Kanyeka, 2001; Kafiriti. 2004; Saidaiah *et al.,* 2010) as well as poor design and management of irrigation facilities (Tesfai et al 2002; Kafiriti. 2004). Poorly designed and managed irrigation local infrastructures are common practices for the majority of farmers in lowland and irrigated rice production (Kafiriti, 2004), and according to (FAO, 2000) such practices result in accumulation of salt in irrigated fields.

4. Salt affected soils management approaches

Worldwide, the research to overcome salt related problems is based on two approaches: (i) rehabilitation of a growing environment suitable for the normal growth of plants; (ii) or select the crop and/or change genetic architecture of the plant so that it could be grown in such areas. The first approach involves major engineering and soil amelioration processes which need a lot of resources which are often out of the reach of small and marginal farmers. Rehabilitation of salt affected soil is too far expensive for a resource poor farmer. For example, it requires about ≈ 300 and 600mm of water to remove 50% and 90% of saline salts, respectively, in the field (Anonymous, 1998).

Use of gypsum has been recommended as one of the ways to combat the salt (sodic) problem. Despite the fact that Tanzania has an abundant local gypsum resource at Makanya in Kilimanjaro region, its use has been confined to the manufacturing of cement. This makes it difficult for the small holder farmer to use gypsum for soil reclamation. Furthermore, about 15 t ha^{-1} of gypsum is required for reclamation of salt affected soil particularly sodic soils (FAO, 2005), which adds more difficulty in application by the poor resource farmers. In addition, experience has revealed that a tolerant cultivar has to be used for 1- 2 years after land reclamation (FAO, 2005).

The second approach i.e. breeding crop varieties with in-built salt tolerance is realized as the most promising, less resource consuming/economical and socially acceptable approach. According to Mishra *et al*. (2006) and Geetha *et al.* (2006), breeding crop varieties for increased salt tolerance is now considered as a more promising, energy-efficient and economical approach than major engineering processes and soil amelioration techniques which are beyond the reach of resource poor farmers. Improving irrigated rice varieties by incorporating tolerance to salt stress will help in achieving the long-term goal of improving rice productivity in the country; so that increased yield levels can be achieved. Genetic improvements which are less costly and permanent can be easily adopted by resource-poor farmers (Rahimi *et al.,* 2010; Sadeghi *et al*., 2009). Lack of preferred high yielding varieties which have been improved for salt tolerance as well as poor water and soil management practices in irrigated fields are some of the factors to which farmers often attribute low production.

5. Importance of rice breeding for salt tolerance in marginal environments of Tanzania

Because of the high probability of low yields and crop failures in unfavorable environments, the use of inputs such as fertilizers, pesticides and weed control is seen by farmers as risky (Cassman, 2004). Therefore, the adoption of "improved agronomic practices" has been very limited. The only economic solution to increase crop yields in unfavorable environments is through breeding for tolerance to the existing stress (Efisue *et al*., 2009). According to Crossa *et al.* (1995), the yielding ability of a variety is the result of its interaction with the prevailing environmental factors such as soil characteristics, moisture, fertility, temperature, and day length which vary over the years and locations. Because of the strong influence of environmental factors during various stages of crop growth (Sadeghi *et al.,* 2010), genotypes differ widely in their response to environments. Studies of rain-fed lowland rice consistently identified large genotype by environment (or location) (G x E) interaction for yield (Crossa *et al.*, 1995). Manney (2004) pointed out that to tackle G x E interaction; breeders usually follow one of two main approaches to produce genotypes that will suit their environments. One approach is to breed for specific adaptability. This strategy is aimed at producing genotypes to suit a defined narrow range of environments. Breeding for general adaptability is another strategy, whereby, genotypes developed would give high yields relative to other cultivars in both favourable and unfavourable environments. The integration of physiological traits in breeding programs for unfavorable environments is one avenue to increase the efficiency of breeding which has been discussed extensively in the literature (Singh, 2001; Siyal *et al.,* 2002).

At the country level, larger increases of national production can be obtained by increasing production in good-quality soil environments through the joint effect of improved cultivars and improved agronomic practices. However, such a strategy will neglect many small and poor farmers in marginal environments who could represent the majority of the farmers in the country. According to Zavala-Garcia *et al.* (1992) and Ceccarelli (1995) it is possible to increase agricultural production at the country level and, at the same time, to serve small, resource-poor farmers by recognizing that the two types of environments need separate breeding programs, with sometimes different objectives, methodologies and type of germplasm. In the case of a typical crop grown in a range of agro-ecologies and currently unpredictable environments such as rice, it is possible to improve yield in the unfavorable environments under farmers' conditions. The key elements are the use of locally adapted germplasm and direct selection in the target environments (Acquaah

2007). However, according to Efisue *et al.* (2008) and Kamau and Migwa (2009) understanding farmer constraints and needs, and incorporation of farmers' opinion in breeding various crops is a prerequisite for high variety adoption.

6. Rationale for research focus

Many efforts have been made elsewhere to improve cultivated rice varieties for salt-tolerance. In Tanzania, such improvement has never been done though the cultivated land is increasingly dwindling due to the effects of current environmental changes which increase the effects of SASs in crops. Most of the cultivated rice varieties grown in Tanzania belong to the Asian *Oryza sativa* and farmers use either improved and/or local varieties regardless of the salt status in the soils. The varieties grown have never been tested or improved for salt tolerance. This results in poor performance of most of the recommended varieties when grown in SASs, the situation which discourages farmers cultivating under these conditions.

Sadegh *et al.* (2010) and Jiang *et al.* (1999) also found that when large differences exist between target environments, a distinct set of genes would be required for specific adaptation (Saidaiah *et al*., 2010). Thus, cultivars selected in non-stressed environments may not necessarily be suited for stress environments (Morris and Bellon 2004). Experience has revealed that the introduction of high yielding varieties from non-stress soils to problem soils, with the aim of increasing production, has not only resulted in yield failure (Manney, 2004), but has also resulted in farmers disappointment on the use of improved varieties (Derera *et al.,* 2006). Therefore, the response to selection is maximised when selection is conducted in the environment where the future variety will be grown. This justifies the urgent need to develop specific salt tolerant cultivars for specific sites according to the specific salt problem, which is the aim of this study.

7. Research goal

The study focuses on contribution to increasing rice productivity, in order to improve food security and livelihoods of resource poor farmers through the use of salt tolerant cultivars in salt- prone rice irrigated areas of Tanzania.

8. Research objectives

The specific objectives were to:

1. determine farmers' perceptions on both salt problems and its effect on rice crop productivity as well as establishing farmers' needs and preferences for rice varieties in the irrigated environment;
2. determine the extent of the salt problem in both soil and irrigation water in the available rice irrigation schemes in the North-eastern Tanzania;
3. identify the major physiological mechanisms associated with salt tolerance in farmer-preferred native varieties and landraces; and
4. determine the mode of inheritance of salt tolerance in rice under different salt soil environments.

9. Research hypotheses

The following hypotheses were tested:

i. Majority of rice irrigation schemes of North-eastern Tanzania are not salt affected.

ii. Smallholder farmers are not aware of SAS problems and their effects on rice productivity.

iii. Farmers do not have specific preferences for rice cultivars.

iv. Different mechanisms for salt tolerance exist among rice genotypes.

v. Genetic variation does not exist for salt tolerance in rice germplasm.

vi. Farmers preferred local rice genotypes have poor combining ability for salt tolerance.

vii. Salt tolerance is controlled by additive genes and there are no maternal effects thatcontributing to the inheritance of salt tolerance.

10. Structure of the thesis

The thesis is designed in parts of chapters and there are six chapters preceded by general introduction to the thesis:

1. Chapter one gives a review of literature on the work that has been done regarding salt stress and the use of salt tolerance cultivar highlighting where the information is lacking.

2. Chapter two contain the information on farmers' characteristics, their perception on salt affected soils, coping strategies, as well as their preferences that determine acceptance and adoption of new salt tolerant varieties.

3. Chapter three provides an understanding the extent of the salt problem in both soil and irrigation water in the rice irrigation schemes; and the proportion affected by salt in the North-eastern Tanzania.

4. Chapter four contain the information on screening of parental genotypes to identify sources of salt tolerance from both local and introduced rice genotypes and major physiological mechanisms associated with their tolerance to salt.

5. Chapter five involve gene action and combining ability studies for yield and associated morpho-physiological trait under salt stress environments.

6. Chapter six contain an overview of research findings.

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Chapter One
Literature review

This literature review provides insight on topics relevant to the research focus to provide the theoretical base for the research on breeding rice for tolerance. The chapter therefore highlights a research context by providing: a) a general over view of salt affected soils and their effects in plants including rice; b) importance of salt tolerant varieties to small-scale farmers and the use of participatory approaches in salt tolerant varieties development; and c) reviewing the literature on screening procedures and genetics of salt tolerance in rice; d) the general information on salt affected soils, their distribution in the country.

1.1 Characteristics of SASs and their effect on rice yields

1.1.1 SASs and their identification

According to Seeling and Richardson (1991), salt-affected soils may contain an excess of water-soluble salts (saline soils), exchangeable sodium (sodic soils) or both an excess of salts and exchangeable sodium (saline-sodic soils) (Table 1.1). A sodic soil has an exchangeable sodium percentage (ESP) in excess of 15; that is, 15 percent or more of the soil's cation-exchange capacity (CEC) is associated with sodium and the remainder with calcium, magnesium, and other cations. Exchangeable sodium in a soil is also reported as the Sodium Adsorption Ratio (SAR). This is a unit-less ratio of the amount of cationic (positive) charge contributed to a soil by sodium to that contributed by calcium plus magnesium. A desirable value for SAR is below 13. The pH (acidity-alkalinity value) of the soil usually is high, often above nine, and plant nutritional imbalances may occur.

On the other hand, salinity is measured by conducting an electrical current through a soil solution made from a soil sample. The ability of the solution to carry a current is called electrical conductivity and is measured in decisiemens per meter (dSm^{-1}). According to the USSL (1954), a soil having an electrical conductivity of the saturated paste extract (ECe) of 4 dS m^{-1} (4 $dSm^{-1} \approx 40$ m*M* NaCl) or more can be described as a saline soil.

One dSm^{-1} is equivalent to millimhos/cm [mmhos/cm]) at 25°C (77°F). The pH values and SARs are much lower than 8 and 13 respectively. A third category of SASs is a combination of saline and sodic soils (Saline – sodic soils), such soils contain large amounts of soluble salts, high sodium in particular, as well as high pH (>8).

Table 1.1 Classification salt-affected soils.

Classification	Electrical Conductivity(ECe) (mmhos/cm)	Sodium Adsorption Ratio (SAR)	pH
Saline	> 4.0	< 13	< 8.5
Sodic	< 4.0	> 13	> 8.5
Saline - Sodic	> 4.0	> 13	< 8.5

Source:(Seelig and Richardson, 1991)

1.1.2 Effects of soil salinity on plant growth

Moradi *et al.* (2003) reported that the saline soils are characterised by white surface crust, good soil tilth, high fertility and poor yield. The white surfaces occur as water evaporates from saline soil salts which were in the water are left behind and accumulate on the soil surface. The excess of these salts keep the clay in a flocculated state so that these soils generally have good physical structure, tillage characteristics and permeability to water, even better than those of non-saline soils (Siyal *et al.,* 2002). In these soils, the salinity does not affect the physical properties of soils but it is harmful because elevated soluble salts in the soil solution reduce the availability of soil water to plants (Moradi *et al.,* 2003; Siyal *et al.,* 2002). Salts tie up high amount of water in the soil and prevent plants from absorbing it by osmotic pressure. Seedlings are the most sensitive to water stress and crop stand is reduced because of seedling death and poor yield (FAO, 2003). Manney (2004) reported salts accumulate to toxic levels thereby enhancing the rate of leaf senescence. Manney (2004) reported further that both initial and long term effects of salt stress lead to a reduced photosynthetic capacity of the plant through a reduction in leaf area, chlorophyll content and stomatal conductance, and eventually low biomass production. Moreover, processes leading to seed germination, seedling growth, flowering and fruit set are also negatively affected (FAO, 2003).

However, the lower the salts content of the soil the lower the dSm^{-1} rating and the less effect on plant growth (FAO, 2005). Studies by Maas (1986) reported that crop yields are not significantly affected where the salt level is 0 to 2 dSm^{-1}. A level of 2 to 4 $dS\ m^{-1}$ restricts some crops. Levels of 4 to 5 dSm^{-1} restrict many crops and above 8 $dS\ m^{-1}$ restrict all but very tolerant crops. According to Chinnusamy *et al*. (2005) most grain crops and vegetables are glycophytes and are highly susceptible to soil salinity above ECe of 2 dSm^{-1}. They reported further that a threshold above which reduction in rice yield is anticipated ranges from 1.9 to 3.0 dSm^{-1} (Chinnusamy *et al*., 2005). Further more, FAO (2005) highlighted yield losses for most salt sensitive crops. The report showed that if the EC (e) is less than 4, the yield loss will be less than 10%; if the EC (e) is more than 6, the yield loss will be 20 – 50% and when the EC (e) is more than 10, then yield loss will be more than 50%.

1.1.3 Effects of soil sodicity on plant growth

These soils seriously affect plant growth in a number of ways: Tesfai *et al.* (2002) reported that the high pH leads to low micronutrient availability and decreases the availability of macronutrients such as calcium, magnesium and phosphorus. On the other hand there is accumulation of elements such as sodium, molybdenum and boron in these soils resulting in direct toxicity and may lead to plant injury or reduced growth and eventually death in more sensitive plants. Furthermore, high pH and excessive sodium are the major characteristics which do not allow soil particles to attach to one another; as a result soil disperses and is not friable (Mnkeni, 1996).

Alkaline soils are very sticky and have a soapy feel when wet and very hard when dry (Moradi *et al.,* 2003; Siyal *et al.,* 2002). Cloudy water in puddles may form on the soil surface of this soil and the surface crust is always black due to dispersion of organic matter (FAO, 2005). According to Tesfai *et al.* (2002) dispersed organic matter may accumulate at the surface of poorly drained areas and impart a black colour; hence the common name 'black alkali soils'. Moreover, these properties reduce water infiltration and aeration in the soils and hinder the growth of roots (Moradi *et al.,* 2003). Siyal *et al.* (2002) added that seed germination in these soils is poor due to poor levelling and difficulty in accomplishment of seedbeds. Moradi *et al.* (2003) reported that soils with high sodium concentration typically are not a problem if the soil also has a very high concentration of calcium and magnesium. Soils high in sodium will be a problem if the calcium and magnesium concentrations are low. According to Singh (2001), sodic soils are deficient in nitrogen, phosphorus, zinc and iron, and have boron toxicity.

1.1.4 Effects of saline-sodic soils on plant growth

Calcareous saline - sodic soils have high levels of soluble salts, calcium carbonates (3-38%) and pH ranging from 7.5 to 11.0 (Singh, 2001). Severe zinc, iron and phosphorus deficiency occurs in such soils (Dobermann and Fairhurst, 2000). However, the soils generally have good physical structure, tillage characteristics and permeability to water. According to Waskom *et al*. (2006), a high pH or basic soil does not look different from soil with neutral pH, adding some difficulties in their identification by farmers. Sometimes the soil may have a powdery substance on the surface and the characteristics of plants growing in these soils sometimes give clues about the problem. High pH reduces the availability of some nutrients (zinc, iron, phosphorus). Signs of high soil pH can be visible in plants, this includes yellow stripes on the middle to upper leaves (signs of zinc and iron deficiency); or dark green or purple colouring of the lower leaves and stems (signs of phosphorus deficiency).

1.1.5 Nutrient imbalances and interactions in rice plant under salt stress

Salt stress disrupts the nutrient balance in the plant. Singh (2001) found that nutrient stresses were caused by synergistic or antagonistic uptake of or the other nutrient. In rice, a deficiency of one nutrient causes increased uptake of a nutrient of the same valence (Singh, 2001). Deficiency and/or toxicity of one element may be induced by surplus or toxicity of another (Gregorio *et al.,* 1997). Under saline conditions, common salt – NaCl, is often the most abundant in soils. This compound in higher concentrations causes water deficit, ion toxicity, ion imbalance or a combination of these factors (Aquaah, 2007). However according to Dobermann and Fairhurst (2000) the critical concentration of salt (NaCl) in leaf tissue, at which toxicity symptoms appear, differs widely between varieties.

Studies have shown that a major part of the NaCl-induced growth inhibition is caused by excess Na ion (Gregorio *et al.,* 1997; Siyal *et al.,* 2002; Moradi *et al.,* 2003; Aquaah, 2007). Under salt stressed conditions, K^+ deficiency increases and Na^+ uptake increases (Dobermann and Fairhurst 2000; Gregorio *et al.* 1997) resulting in plant injury, sterility and yield reductions. Gregorio *et al.* (1997) reported further that there is a natural tendency in all the cells to accumulate K^+ and exclude Na^+ ions for maintaining favourable Na^+ /K^+ ratios. Presence of higher concentrations of Na^+ in the growth medium upsets this balance. Excess Na^+ may compete with K^+ in membrane transport and when accumulated in the cytoplasm, it inhibits many enzymes. Devitt *et al.* (1981) found that Na^+ /K^+ imbalance adversely affects grain yield. On the other hand, a study by Pareek *et al.*(1997) revealed that presence of Ca^{++} in the growth medium enhances the selective absorption of K^+ by plants at high concentrations of NaCl. Gregorio *et al.,* (1997) reported that salt injury in rice plants is caused by both osmotic imbalance and accumulation of chloride (Cl) ions. However, recent studies indicated that injury was due to the excessive sodium (Na) uptake, and chloride, being essentially a neutral anion, is tolerated over a wide range of concentrations.

Due to high levels of these salts in soils, the genetic potential of the plant is not realized to its maximal extent towards tapping the grain yield (Tollenaar and Lee, 2002), hence reduction in yield. Mkeni (1996) reported that the majority of farmers cultivating in SASs areas have low level of understanding of salt affected soils, symptoms and their effects in plant growth. It has been reported further in these salt stress environments that, farmers tend to confuse the symptoms due to SASs and nutrient stresses (Mwende, personal communication). Thus, suggesting the need to understand farmers' perception and behaviour under SAS community for proper planning on mitigation measures.

1.2 Importance of salt tolerant varieties in the small-scale farming sector

Breeding for sustainability has been defined as a process of fitting cultivars to an environment instead of altering the environment (by adding fertilizer, water, pesticides, etc.) to fit cultivars (Coffman and Smith, 1991). It has been also recognized that the key to increased production with fewer external inputs, a condition which is more selfsustaining, less harmful to the environment, and yet productive enough to meet the increasing demand for food, will be through developing stress tolerant cultivar (Efisue *et al*., 2008) and evaluating of the identified under farmers' condition (Bramel-Cox, *et al*. 1991) where the majority are cultivating their crops in stressful marginal environments. Scientists from developing countries have been trained on breeding methods and philosophies which have been successfully used in favorable conditions (Ceccarelli, 1995). As a consequence, in most developing countries experiment stations are concentrated in the most favorable environments. The few which are in marginal environments are managed according to "recommended" agronomic practices and yield levels are much higher than in farmers' fields. Both theory and experimental data show that this type of breeding has a low probability of success in unfavorable conditions because of differential genotype behaviour in these marginal unfavorable environments (Ceccarelli, 1995).

Breeding for salt tolerant crops is one of the cheap and useful and long term solutions to resource poor farmers in salt soil affected areas (Mahmood *et al*., 2004). For increasing rice yield potential, present high yielding farmers' preferred rice varieties can be modified and improved for salt tolerance (Manney, 2004). For example, farmers of the saline affected coastal region of Bangladesh usually cultivate salt tolerant varieties and harvest about 2.0-2.5 t ha^{-1}/year from the areas which would results into zero yield with the high yielding non-salt tolerant varieties (Sen, 2004). Ponnamperuma (1994) reported that the use of salt tolerant varieties will help the farmers to cultivate on their abandoned fields and also the high yield salt tolerant varieties are expected to provide a yield increase of about 2 t ha^{-1} in these soils.

1.3 Significance of Participatory Research for technology development

Participatory rural appraisal (PRA) is being used as a tool for involving communities in the varietal development processes. Participatory rural appraisal is an approach, which emphasises local knowledge and assistance to local people to make their own appraisal, analysis and plans. Effective breeding should be firmly based on clear identification of farmers' perceived constraints and their preferences for cultivars through interactive breeding and research. In participatory crop breeding, farmers provided important information on plant types, desired traits and insight into trade-offs they are willing to make in designing cultivars for their area (Sperling *et al*., 2001).

Studies have reported the increase in varieties adoption by farmers' involvement in varieties development processes. For example, according to Witcombe *et al*. (1996), farmers were reported to have been involved in rice varietal selection in India and Nepal which increased the adoption of new variety. Fashola *et al.* (2007) found that PRA was practical and used to study socio-economic factors influencing the adoption of sawah rice production technology in Nigeria. Banziger and de Meyer (2002) reported that farmers participated in the evaluation of pre-selected maize cultivars in CIMMYT's (International Maize and Wheat Improvement Center) mother-and-baby trials in Southern Africa. Monyo *et al*. (2001) reported that farmers were engaged in pearl-millet (*Pennisetum glaucum* L.) cultivar selection in Namibia. Therefore PRA is considered as a powerful tool for surveillance to understand the farmers' important information on constraint, needs and preferences and considered as vital means to generate information on farmers' awareness on the SASs and their effects among farmers in irrigated rice farmers' communities.

Social scientists investigating farmers' adoption behaviours have accumulated considerable evidence showing that demographic variables, technology characteristics, information sources, knowledge, awareness, attitude and group influences affect adoption behaviour. Adoption of innovations refers to the decision to apply an innovation and to continue to use it (Fashola *et al.,* 2007). Adoption studies (Azuma, 2004) have identified farm and technology specific factors, institutional, policy variables and environmental factors to explain the patterns and intensity of adoption. Adoption has been determined through variables such as gender, level of formal education, household size, farm size and wealth level. Therefore, understanding farmers' characteristics and their economy plus their involvement in the technology development process is central for success in the adoption of farm technologies (Fashola *et al.,* 2007). The eventual decision of farmers to adopt or not will depend on their attitude to the innovation, farming experience, household size and visits by extension agents (Azuma, 2004).

Ignoring farmers need may lead to low adoption rate of developed cultivars. According to Efisue *et al.* (2008), the low adoption rate of rice varieties by the farmers could be attributed to the lack of understanding of the variations of rice culture in the region or due to the fact that scientists are working in isolation from farmers and other stakeholders and therefore, might not identify the unique requirements for the subsistence farmers in particular niches of the diverse environments. For example Kamau and Migwa (2009) reported that most farmers utilized the cassava landraces despite availability of modern varieties. In Zimbabwe, farmers were also growing old maize hybrids released in the 1970s and their own landraces in spite of availability of new and high-yielding hybrids (Derera *et al.*, 2006).

1.4 Salt stress tolerance and Selection strategies

According to Tollenaar and Lee (2002), stress tolerance is the ability of cultivars to mitigate the impact of stress. Under salt stress conditions, the difference between "yield potential" and "actual yield" reflects the level of stress tolerance of a cultivar. Thus, as the actual yield approaches yield potential, cultivars are regarded as relatively stress tolerant (Tollenaar and Lee, 2002). There is overwhelming evidences in support of the predominance of salt stress tolerance in explaining yield improvement in rice (Singh, 2001; Siyal *et al.,* 2002; Moradi *et al.,* 2003). Studies have shown that salt tolerance varies considerably with the developmental stages in a number of species including rice (Flowers, 2004). Rice is comparatively tolerant of salt stress during germination, active tillering, and towards maturity and is sensitive during early seedling and reproductive stages, however genetic variation exist between genotype (Grattan *et al.,* 2002; Chinnusamy *et al.,* 2005). Bayuelo-Jimenez *et al.* (2002) found that tolerance at emergence followed by seedling survival and establishment are important in the maintenance of optimal crop stand in the field, and ultimately the economic yield. It is therefore important for the current breeding program to evaluate the performance of the breeding material in order to understand and establish their tolerance behaviour at different growth stages of the plant.

1.4.1 Major genotype evaluation criteria

The criteria used to evaluate the salt tolerance potential of any plant species are morphological, physiological, and biochemical in nature (Flowers, 2004). The morphological criteria include stunted growth (Boyd and Rogers, 2004), leaf scorch and chlorosis of green parts and necrosis of leaves (Chen *et al.,* 2003). Physiological criteria are tissue ionic contents and photosynthetic rate whereas the biochemical ones include qualitative and quantitative changes in proteins, fats, and carbohydrate patterns (Flowers, 2004; Singh, 2001). The physiological bases of salt tolerance during early seedling stage are fairly well understood. According to Singh (2001) key traits include high seedling vigor, salt exclusion at the root level, compartmentation of ions in older leaves, high tissue tolerance, responsive stomata that close within minutes after exposure to salt stress but partially reopen after a period of acclimation, and up regulation of antioxidant systems, particularly the ascorbate/glutathione pathway of oxidative stress tolerance. Yeo and Flowers (1986) found that during reproductive development, tolerant genotypes tended to exclude salt hence less salt concentration in flag leaves and developing panicles, resulting in higher grain yield.

Studies also showed that the typical mechanism of salt tolerance in rice was the exclusion or reduction of Na^+ uptake and increased absorption of K^+ to maintain a good Na^+/K^+ balance in the shoot (Gregorio *et al.,* 1997). Dobermann and Fairhurst (2000) reported that the correlation between Na^+/ K^+ ratio and salinity tolerance has been established; however, no absolute critical levels in plant tissue are known. A Na^+/ K^+ ratio of $<2:1$ in the grain may indicate a salt tolerant rice variety. Dobermann and Fairhurst (2000) reported further that varieties showing the greatest tolerance for salt within plant tissues are not necessarily those showing the greatest overall phenotypic resistance to salinity.

Studies by Gregorio *et al. (*1997) observed that salinity suppresses leaf elongation and formation of new leaves, plant height, root length, tillering ability, and biomass at vegetative stage and at reproductive stage salinity causes an increase in sterile florets by affecting panicle initiation, spikelet formation, fertilization, and germination of pollen. Salinity also reduces panicle length, number of primary branches and spikelets per panicle, fertility and panicle weight, thus reducing grain yield (Geetha *et al*., 2006; Muhammad *et al.,* 2010). Nevertheless, Gregorio *et al*. (1997) and Flower and Yeo (1981) reported the vast genetic variability among genotypes in rice which makes it amenable to genetic manipulation to further enhance its tolerance. This suggests the importance of evaluating for the key tolerant traits existing in parental materials which will be used in a breeding program.

1.4.2 Traits for tolerance in rice plant

Improving a given crop or cultivated species for salt tolerance involves reliable screening procedures to search amongst natural diversity within the species, or closely related and inter - fertile species. In this case screening for a trait associated with a specific mechanism is preferable to screening for salt tolerance itself (Chaubey and Senadhira, 1994). Traits for salt tolerance that have been commonly used to identify tolerant germplasm collections have included seedling vigour, shoot and root length, number of productive tillers, culm strength, rates of Na^+ or Cl^- accumulation in leaves, degree of leaf injury and spikelet sterility (Gregorio *et al.,* 1997; Chaubey and Senadhira, 1994; Jennings *et al.,* 1979). The most successful relate to rates of Na^+ accumulation in leaves (Chaubey and Senadhira, 1994). Sodium accumulation in leaves has been shown to relate to salt tolerance in genotypes of rice (Yeo and Flowers, 1989). Furthermore, Mishra *et al.* (2006) found low Na^+/K^+ ratio of ion uptake was positively correlated with a high level of salt tolerance and was taken into consideration as a desired characteristic while screening the lines.

Early vegetative vigor is important as it is associated with various combinations of rapid seedling emergence and early development and heavy tillering, early and rapid increase in seedling height (Jennings *et al.,* 1979). Plants with early vegetative vigour are desirable if such vigour does not carry through to excessive growth to mutual shading after panicle initiation. Yeo *et al*. (1990) assessed some physiological characters for their use in screening and reported that plant vigour was strongly correlated with survival, and concluded that fast growth in vigorous plants increased salt dilution in plant tissues and therefore increases the ability to cope with salinity.

Rice farmers prefer a combination of high tillering and compact or non-spreading culm that are moderately erect. Jennings *et al.* (1979) reported that in improved rice cultivars, heavy tillering is preferred over medium to low tillering. At heavy seed or seedling densities, which are necessary for high rice yields, profusely tillering varieties will form few culms per plant but still produce more in total than low tillering varieties. Zeng *et al.* (2001) observed a significant reduction in tiller number per plant when rice plants were salinized for 20 days.

Spikelet fertility is an obvious prerequisite for high yield in both non-stress and stress soils. In non-stress and good crop management, high yields are obtained with normal spikelet sterility of as much as 10 to 15% (Mishra *et al.*, 2006). Sterility is common in rice breeding and can be caused by stresses like salt, drought and extreme temperatures, lodging, and hybrid sterility or genetic incompatibility (Jennings *et al.,* 1979). High percentage of spikelet sterility relates to a low level of salt tolerance and was used in rice evaluation (Acquaah, 2007; Mishra *et al.,* 2006). In addition, recording 50% flowering date is another trait which gives an accurate measure of total maturity period as the period from flowering to grain maturity is relatively constant among lines (Jennings *et al.,* 1979).

Yeo *et al.* (1990) commented further that the traits for salt tolerance were essentially independent, none of the known salt-tolerant landraces combine favourably more than few of them. Furthermore, there is considerable variation in the extent of expression of particular traits among cultivars, suggesting screening of the materials to identify better donors and of useful genes for genotype improvement (Yeo *et al.,* 1990). Moradi *et al.* (2003) later found that salinity tolerance at the seedling and reproductive stages are only weakly associated; hence, pyramiding of contributing traits at both stages is needed for developing resilient salt-tolerant cultivars.

1.4.3 Potential for landraces and plant introductions as sources of salt tolerance

Differences in varietal tolerance to salts and other adverse soil conditions have been known to exist for decades. It is only in the latest decades that serious efforts have been initiated to exploit the genetic potential of salt-tolerant crop varieties through different breeding programmes (Gregorio and Senadhira, 1993; Yeo and Flowers, 1986). These differences can be exploited among other methods through wide collection and evaluation of different varieties and landraces (Singh, 2001) and /or the use of plant introductions. According to Ferh (1987), heterogeneous plant introductions obtained through exchange also provide an opportunity for selection of superior individuals that are useful as cultivars.

In rice, out of a considerable number of landraces collected from different salt affected rice lands of India, about 18 salt tolerant varieties have been developed through pure line selection and have been introduced to other countries as varieties or donors of salt tolerance (Bandyopadhyay and Sinha, 1985). Furthermore, some tolerant rice varieties such as Pokalli, Getu, Damodar, Patnai 23 are selections from landraces (Bandyopadhyay and Sinha, 1985). In Sri lank, three elite rice lines developed for tolerance to salinity from a cross made between BG94-1 and Pokkali has been released in 1989 for cultivation in coastal saline areas (Chaubey and Senadhira, 1994). Chaubey and Senadhira (1994) reported further that the majority of traditional varieties grown on problem soils of south and southern East Asia appear to have originated from India and Thailand. Varieties grown in most irrigated schemes of the North eastern Tanzania combines those from national breeding programmes, introduction and land races. However their status regarding to salt tolerance has not been established. Therefore, understanding the salt tolerance potentials of the existing cultivars and introductions is prerequisite for development of salt tolerance rice genotypes.

1.4.4 Genotype screening methods

Screening has been done to select donors as well as breeding lines used in hybridization programme. For example breeding lines were screened for various traits like salinity, sodicity/alkalinity, Fe, Al, Mn and B toxicity as well as P, Zn, and Fe deficiencies to understand the level of tolerance before hybridization (DeDatta *et al.*, 1994). However, quantification of salt tolerance has always been difficult (Flowers and Flowers, 2005; Yeo *et al.*, 1990). Field screening for salinity and sodicity is problematic as the distribution of ions, both vertically in the soil profile and horizontally across the field, is notoriously variable. In addition, rainfall or dry weather at different times of the season adds further confounding factors (Flowers and Flowers, 2005; Gregorio and Senadhira, 1993; Yeo *et al.*, 1990; Yeo and Flowers, 1986). Therefore laboratory techniques as well as pot and solution culture are common greenhouse techniques for screening genotypes under controlled conditions (Singh and Chatrath, 2001; Chaubey and Senadhira, 1994).

In rice, tolerance to salt stress as stated earlier varies with the stage of development and the seedling stage is the most sensitive phase of plant development. Therefore, almost all work on salt tolerance in different crop species reported has included plant assessment at this stage (Singh and Chatrath, 2001; Gregorio and Senadhira, 1993). Gregorio *et al.* (1997) developed a fast and easy screening technique based on the ability of seedling to grow in salinized nutrient solution whereby voluminous materials can be screened in a short time. However, these systems may not be useful in traits associated with root-soils interactions (Singh and Chatrath, 2001).

Munns and James (2003) described their preferred system comprising gravel-filled pots, supporting the plants and allowing aeration, set into trays which were cylindrically sub-irrigated with saline solution introduced gradually after germination. In another experiment, Munns and James (2003) reported that soil variability was handled by excavation of large beds, filled with defined soil mix and irrigated with a consistent water source. Minshra *et al.* (2006) reported their field evaluation method where by a barren sodic affected land was used for rice screening.

1.4.5 The need for appropriate breeding source germplasm

Cultivar development relies on the presence of genetic variability for the traits under consideration. This makes it imperative to evaluate germplasm collections for grain yield potential and performance under salt soil condition to select the appropriate parents for the breeding programme. The next step is to understand the gene action controlling the traits of interest. This information can be obtained by conducting combining ability studies that entails systematic crossing of the selected parents using appropriate mating designs and subsequent hybrid evaluation. Information on general combining ability

(GCA) and specific combining ability (SCA) effects is critical in cultivar development, either through selection or cross breeding (Arunga *et al.,* 2010). However, in self pollinated crops the use of SCA may not be important in these crops except only in hybrid production and GCA is more important as representing a fixable portion in pure line selection. Potential use of GCA and SCA in cultivar development has been reported by earlier studies in rice (Kumar *et al*., 2007; Pradhan *et al.,* 2006; Mahmood *et al.,* 2004) and other different crop species (Sadeghi *et al*., 2009)

Variation due to GCA is attributed to additive genes, and that due to SCA is attributed to non-additive gene action. A survey of literature shows limited information of the kind which eventually limits research under Sub Saharan African arid and semiarid irrigated rice growing conditions. Although a lot of work has been done on the inheritance of salt tolerant traits elsewhere, no work has been reported on the salt tolerant traits under Sub-Saharan environments. In the long run, the development of breeding lines with high grain yield potential and salt tolerance is a key to the rice cultivar breeding programme for arid and semiarid environments of Tanzania.

1.5 Genetics of salt tolerance in rice

The uptake, accumulation and utilization of mineral elements in plants are genetically controlled, although there are is a strong environmental interaction (Chaubey and Senadhira, 1994). Knowledge of the inheritance of tolerance for salt stresses helps in determining the most suitable procedure to be followed in breeding for tolerance to such stress. Besides, farmer preferred varieties that would combine sufficient tolerance to salt stress with other important traits is equally maintained (Jones, 1986). According to Flower and Yeo (1995) the importance of salt tolerance as a breeding objective is likely to increase in future due to progressive environmental changes. Information on the nature and the magnitude of genetic variability present in the available genetic material is thus important for the initiation of any effective selection programme.

Salt tolerance is a complex character which changes with plant age and it is controlled by a number of genes or groups of genes, and involves a number of component traits which are likely to be quantitative in nature (Flower and Yeo, 1995). Genetic variation has been reported to exist for salt tolerance among rice genotypes (Flower and Yeo, 1995), and significant progress has been made in understanding the genetics of tolerance to salt in rice plants (Moradi *et al.*, 2003; Flower and Yeo, 1995).

Jones (1986) also studied the genetics of saline tolerance in two mangrove varieties, viz. Pokkali and Pa Merr 108A in Siera Leone using relative root lengths as a criterion for measuring salt tolerance in saline and non saline conditions. The study indicated additive genetic variation, maternal effects, and transgressive segregation exists in their materials. Yeo *et al.* (1990) demonstrated genetic diversity for sodium uptake and commented that salt tolerance persists within modern rice cultivars and observed additive effects with high heritability in rice shoot strength, shoot and root dry weight as well as Na^+ and Ca^{++} content in the shoot at seedling stage. Mahmood *et al.* (2002) reported that non additive gene effects were more pronounced for panicle fertility, days to maturity; shoot dry weight, paddy yield, Na^+ and Na^+/K^+ ratio. Mahmood *et al.* (2004) found that both additive and dominance effects were important for characters such as Plant height, panicle length, shoot Na^+ and K^+ concentration. Mishra (1991) reported similar results under saline- sodic environments. Likewise Geetha *et al.*(2006) carried out genetic analysis under sodic environment and indicated that both additive and non-additive gene action governing sodicity tolerance in terns of grain yield. Gregario and Senadhira (1993) reported the genetics of salinity tolerance in a Nona Borka, Pokkali, and SR 26B using culture solution method and Na^+/K^+ ratio was used as a criterion for selecting parents with high general and specific combining abilities. Their study revealed that improved lines were good general combiners and reciprocal differences were observed, suggesting tolerant plants should be used as females.

A survey of the literature revealed that substantial research on gene action has been carried out outside Africa and a few studies in West Africa, however, none has been carried out in Sub-saharan Africa environment particularly East Africa. Furthermore, modest research has been conducted on gene action under saline-sodic soil environments. To large extent information about inheritance should be generated from these areas since they are expanding in sub-Saharan environments. According to Falconer (1981) information from genetic studies is specific to the specific germplasm and the environments tested. Thus, information generated in the environments elsewhere might not have direct application in East and Southern Africa where the majority of the countries are planning for irrigated agricultural expansion.

1.6 Origin and distribution of SASs

Salt affected soil (SASs) is simply defined as a soil that has been adversely modified for the growth of most crop plants by presence of soluble salts (Saline or solonchak soils), exchangeable sodium (Sodic or alkali or solonetz), or both (Saline-sodic) (Siyal *et al.,* 2002; Tesfai *et al.,* 2002; Waskom *et al.,* 2006). Soil affected soils (SASs) may have a natural origin (called primary salinity) as a result of weathering of parent materials that are rich in soluble salts or human-aided (secondary salinity) that occurs as a result of agricultural activities, especially with impure (salt rich) water. Waskom *et al.* (2006) reported that salts released through weathering in the arid regions with limited rainfall are usually deposited at some depth in the soil profile, whereby depth of deposition depends on such factors as the water retention capacity of the soil, seasonal, annual and maximum rainfall, etc. If the salts are deposited beyond the rooting zone of most crops, say below 150 cm, they rarely affect the crops. Sahin *et al.* (2002) reported that scarcity, variability and unreliability of rainfall and high potential evapotranspiration in semi-arid and arid areas of the world, affects the water and salt balance of the soil. According to FAO (2000) in arid regions, various types of soluble (Na, Mg and Ca) salts are concentrated in chloride and sulphate forms resulting into soil salinisation. In less arid climates, the soluble salts are less concentrated and Na dominates in carbonate and bicarbonate forms which enhance the formation of sodic soils.

Salt-affected lands occur on all continents of the world in practically all climatic regions, from the humid tropics to the Polar Regions. They can be found at different altitudes, from below sea level (e.g., around the Dead Sea) to mountains rising above 5000 meters, such as the Rocky Mountains (Singh and Chatrath, 2001). Consequently, global estimates on salt affected area vary widely (Yeo and Flowers, 1986). In general about 7% of the total soil surface area of the world is covered by salt affected lands: Australia 42.3%, Asia 21%, South America 7.6%, Africa 3.5%, North America 0.9%, Central America 0.7% and Europe 4.6% (Szabolcs, 1994). Of nearly 160 million hectares of cultivated land under irrigation worldwide, about one-third is already affected by salt, which makes SASs a major constraint to food production (Mnkeni, 1996).

1.6.1 Extent of salt affected soils in Tanzania

Generally, little information on the distribution of SASs in Tanzania is available. The first attempt to obtain SASs information in Tanzania was done by Masoud (1974) using the FAO/UNESCO soil map of the world. The report shows that 3.6 million ha of land in Tanzania has salt problems (De Pauw, 1984). A report by De Pauw (1984) indicated the occurrence of these soils to be most extensive in areas with arid and semi-arid climates. FAO (2000) estimates the actual extent of the salt-affected soils in Tanzania at 1.7 million ha for saline soils and 300 000 ha for sodic soils. However, local estimation gives an area of 2.9 million ha and 700 000 ha for saline and sodic soils respectively. In 2003, FAO reported a total of 3.5 million ha affected by salt in the country where 2.9 million ha are saline. The variation in these figures indicates that the extent of salt affected soils has not been properly documented. Estimates suggest that 5 million ha are potentially suitable for irrigation in Tanzania. So far only 190 000 of this land is actually being irrigated in different schemes (FAO, 2001).

Irrigated agriculture takes on a special importance in this regard as it has a high yield per unit area and is less dependent on the uncertainties of weather notably floods and drought. According to Mnkeni (1996) irrigated agriculture is one of the most affected sectors especially in semi-arid areas of the country. Ten estates in Tanzania are already encountering major salt related problems (FAO, 2003). Furthermore, several smaller irrigation schemes classified as traditional irrigation schemes, which are community managed are experiencing reduced rice yields due to salt (saline and sodic) problems. In regions like Kilimanjaro, some fields in these schemes have already been abandoned because of the effects of hostile soil conditions (FAO, 2003; FAO, 2005). Very limited efforts have been made to overcome the problem.

In the North-eastern part of the country these soils occur mainly, in the lowlands of alluvial plains and valleys such as Pangani river basin and other low land areas of Pare and Usambara mountains (Figure 1.1). Mnkeni (1996) reported SASs in the northern part of the country occur in the low land of alluvial plains and valleys around Mt Kilimanjaro and Meru. Their occurrence is largely due to the fact that head-waters of the river valleys

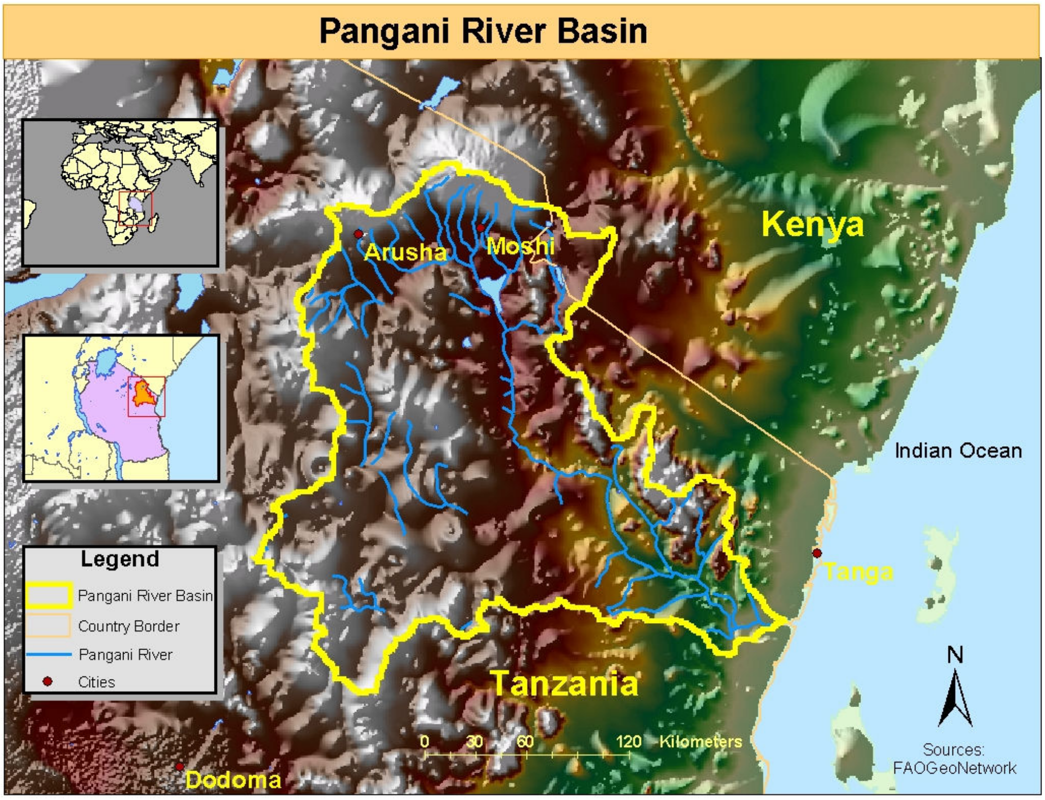

Figure 1.1 Pangani river basin in North-eastern Tanzania *(adapted from Belden et al., 2004)*

lie on volcanic lava and ashes. These lavas weather rapidly so that water draining from the mountains carries with it large quantities of salt. After leaving the mountain slopes, the river crosses through a flattish area of low rainfall. During the dry seasons water evaporates leaving behind salt in the soils. According to Makoi and Ndakidemi (2007) the land area for food production particularly in the low land of Kilimanjaro remain fixed and are decreasing because of human activities which contribute to an increase in salt soil toxicities. Salt affected soils have also been found in other areas of the country including internal drainage basins such as the rift valleys in Arusha region and Bahi swamps in

Dodoma. In these areas salts accumulate as a result of continuous collection of drainage water. Since the drainage is poor water evaporates and salts are left behind

The occurrence of SASs across the country has been associated with various factors. FAO (2001) summarizes the factors into three groups: (a) climate and inherent soil properties: in some parts of Tanzania soils become salted either because of the aridity of the surrounding environment or the soils have developed from a parent material which is more prone to development of salinity and sodicity, (b) landform/topography of the area and (c) man-made causes including poor designing and management of the irrigation infrastructures, seepage from irrigation canals and drainage (Makoi and Ndakidemi, 2007).

1.6.2 Potential for irrigation water quality in salt soil development

Modest information on irrigation water quality is available for most irrigation schemes of The Northern Tanzania. Studies by Buckland (2002) found water to be safe for supplemental irrigation if the electrical conductivity of the water (Ec_w) was less than or equal to 1.0 dSm^{-1} and the sodium adsorption ratio (SAR) less than or equal to 5. If Ec_w is greater than or equal to 2.0 dSm^{-1} and/or SAR is greater than or equal to 10, the water is unsuitable for irrigation. They also indicated that saline-sodic irrigation water with Ec_w between 1.0 to 2.0 dSm^{-1} and SAR of 5 to 10 may negatively affect the structural stability of the soil. Buckland (2002), therefore, recommended that soil structural stability should be determined annually if these waters are used for irrigation.

Marcum (1999a) found that salts can quickly accumulate in the soil profile when irrigating with saline water, particularly when evaporative demand is high. For example, the application and evaporation of 2.5 cm of irrigation water having an EC_w value of 2 dS m^{-1} will deposit ~3.0 kg of salt within a 93 m^2 (1000 ft^2) area. Soil and irrigation water diagnosis is not a common practice particularly in rice irrigation schemes of the country, which is why the current information of the quality of the water used for irrigation purposes and soils in terms salt affected soils characteristics are lacking in most schemes, therefore the need exists to understand the types and level of salts in both soil and irrigation water for suitable variety development. Buckland (2002) therefore suggested that soil and water analyses in irrigated fields are useful not only for determining the suitability of a site for rice planting and, in an established rice field but also for continuous diagnosing problems caused by salts for appropriate corrective measures.

This review of the literature shows that though a lot of work might have been done on salt tolerance in rice, however, breeding for salt tolerant rice in sub-Saharan Africa still remains a necessity, and more genetic and applied breeding studies need to be conducted to avert crop losses.

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Chapter Two

Characterization of rice-based farm economy, perceptions of agriculture constraints and variety preferences in salt affected areas of North-eastern Tanzania

Abstract

Excessive accumulation of salts from improper soil and water management is a common problem in irrigated rice ecosystems which negatively impact on yield. This calls for breeding suitable varieties among other intervation strategies.However, farmers' perceptions about these problems, and prefferences for varieties have not been established in Tanzania. The present study therefore, determined (i) farm economy characteristics in salt affected soils (SASs) communities and establish the potential crops grown, (ii) rice production constraints and farmers' perception on SASs problems, (iii) farmers' needs and preferences for rice varieties, (iv) understand the access to and the use of improved agriculture practices. A survey was undertaken using both participatory rural appraisal and structured interviews. Two villages in Korogwe district-Tanga Region were involved in the study. Results showed that rice and maize were the major staple foods in the area but rice was the more profitable crop. Its consumption was higher than any other crop and it was grown by 100% of the surveyed households. More than 45% of rice produced in the region came from these villages of which 67% was produced in irrigation schemes. Soil degradation through increased salt affected soils and drought were identified as the major factors responsible for irrigated rice yield decline in both villages. Sixty percent of respondents had rice fields affected by salts, and reported yield losses between 40 to 95% due to salt damage. However, 88% of the total respondents were aware of the problem and 48% claimed that the problem was increasing. Major varieties grown included: 1R56, IR54, IR64 and TXD 306 (SARO 5). These varieties are high yielding but susceptible to salt damage. The study revealed that most preferred traits of rice cultivars were high yield potential, early maturing, medium plant stature, tolerance to salt and drought. Improvement of these characters in new varieties for salt tolerance would enhance productivity with likely positive impact on small scale farmers' food security, incomes and livelihoods.

2.0 Introduction

The production of rice in Tanzania is dominated by small-scale farmers in marginal areas. Kanyeka (2001) and Msomba *et al.* (2002) reported that more than 90% of rice in the country is cultivated by smallholder peasant farmers mainly using traditional irrigation systems on small holdings ranging between 0.25 - 2.ha. Small-scale paddy farming is normally done in lowlands using traditional or improved small scale irrigation facilities or entirely depending on rainfall (Msomba *et al*, 2002 and Kafiriti, 2004). According to Alam (2006) and Singh (2001), the traditional irrigation schemes especially under arid and semiarid environments are experiencing increasing levels of salt-affected soil because of mismanagement of the soils, irrigation and drainage principles, poorly designed and managed irrigation infrastructures, excessive and irrational use of irrigation water and also due to global climatic change (FAO, 2000; FAO, 2003).

Given highly variable conditions, stress-prone environments and limited resources under which the crop is grown, productivity is low. Paddy yield averaging below 1.5 t ha^{-1} have been reported in the country (Kanyeka, 2001; Msomba *et al.,* 2002; FAO, 2003; Kafiriti, 2004). Yields as high as 5 tha^{-1} have been reported in some irrigation schemes in the country (Kanyeka, 2001). Though rice contributes a significant proportion of the food requirements of the population, production capacity is far below national requirements. In many developing countries, yield of paddy rice in irrigated area is only 4 to 6 tons per hectare, while the potential yield of modern rice varieties is 10 to 11 tons under tropical humid conditions (Fashola *et al.,* 2007). According to Efisue *et al.* (2008) the production deficit can be overcome by the use of improved, high-yielding varieties adaptable to the production ecologies. However, studies have reported low adoption rate of improved varieties by the farmers in various crops such as rice (Paris and Atlin, 2002; Kafiriti, 2004; Fashola *et al.,* 2007; Efisue *et al* 2008), maize (Derera *et al.,* 2006) and cassava varieties (Kamau and Migwa, 2009).

Several hypotheses regarding the adoption of improved varieties have been put forward (Derera *et al.,* 2006; Efisue *et al.,* 2008; FAO, 2009). One of the main reasons for this low rate of adoption seemed to be the fact that breeders fail to consider the special preferences for farmers especially those in the marginal areas (Derera *et al.,* 2006). Secondly, all the research work has been carried out by breeders at the experimental station, whereby the evaluation agenda and criteria are defined by the researcher. Thus the "promising" varieties brought to the growers/farmers reflected the breeder's opinion (FAO, 2009). Thirdly, varieties selected on research station may not perform well under farmers' field and management conditions (Morris and Bellon, 2004).

Most of the rice cultivars grown in the North eastern Tanzania are improved for high yields and tolerance to pest and diseases. According to Manu-Aduening *et al.* (2006) traits such as high yielding and tolerance to pests and diseases may not be adequate to ensure adoption of improved varieties. Environmental degradation such as: deterioration of water resources, loss of soil resource (such as an increase in salt affected soils), pollution, and night time temperature elevation due to global warming result increases in production constraints (Cassman, 2004), and has to be taken into account for varieties development. It has been further observed that farmers in most areas with edaphic problems have low level of understanding on soil qualities in relation to soil affected soils (SASs) (Mnkeni, 1996).

Therefore, understanding farmer constraints and needs, and incorporation of farmers' opinion in breeding various crops is prerequisite as a way of encouraging variety adoption (Efisue *et al.,* 2008, Kamau and Migwa, 2009). This has becoming increasingly popular and effective in terms of cost and transferring the right varieties and technology to farmers. According to Derera *et al.* (2006) farmers would require varieties that perform well both in the markets and under stress environments. The market ideotype identifies desirable traits such as quality, while the stress ideotype identifies the characters required to fit the cultivar into its target environment, especially climate, soil, disease and pests. Environmental factors (non-genetic factors) are diverse, therefore may have positive or negative impacts on genotypes. Such a situation suggests that the improved varieties for one environment might not be adequately satisfying farmers' needs and preferences in another environment (Witcombe *et al.,* 2003).

A participatory rural appraisal (PRA) (Chambers, 1992) was introduced with the aim of narrowing the communication gap between scientists and farmers. Various efforts are being made to reduce this gap, in particular by participatory plant breeding (Sperling *et al.,* 2001). For example through PRA Kafiriti (2004) reported that farmers in south-eastern Tanzania preferred and selected varieties with short to medium maturity period, which produce many tillers and mature uniformly; and with long translucent aromatic grains for their own use and marketing. According to Efisue *et al.* (2006), in irrigated rice ecology, high grain yield was the most preferred trait followed by long duration, whereas farmers' high preference for tall varieties in the upland and lowland ecologies was also in sharp contrast with the model of dwarf rice varieties responsible for the green revolution in Asia. Cools *et al*. (2003) showed that farmers' knowledge could further be integrated into soil related problems identification and land evaluation for crop suitability; in their study the insights gained through the PRA were complementary to the formal land evaluation.

Kafitiri (2004) reported further that the PRA was used to generate useful information regarding soil quality and provided insights into farmers' soil diagnosis and classification; according to their studies farmers identified soil related problems in rice productivity based on texture, colour, taste and which is intricately linked to crop soil suitability. These suggest farmers can provide vital information on the existing problem, plant types, desired traits and insight into trade–offs they are willing to make among traits in designing cultivar types (Sperling *et al.,* 2001) which has been shown in other crops. Participatory methods are preferred to generate such information as they recognize the value of farmers' local knowledge, their interests and ability to experiment and innovate, and their exchange of information and technology (Fashola *et al.,* 2007). The overall objective of this study was therfore to improve researchers' understanding of the existing production constraints in relation to SASs development, cultivars preferences and selection criteria so as to contribute most effectively to improvement of rice crop for irrigated areas of North Eastern Tanzania.

The objective of the study is therefore to:

i) understand the potential crops, rice based farm economy characteristics and rice production constraints;

ii) determine farmers' perception on salt problems and the effect of salt affected soil in rice crop productivity;

iii) establish farmers' needs and preferences for rice varieties in the targeted irrigation environment; and

iv) explore accessibility and the of improved agriculture practices.

2.1 Material and methods

The study was conducted in two phases which included participatory rural appraisal (PRA) - a suitable tool in the context of exploratory and discovery purposes (Phillips, 1968) and formal survey using standardized interview which is advantageous in the context of validation (Theis and Grady, 1991). Both formal and informal approaches were employed in data collection in order to enhance precision and high evidential value.

2.1.1 Research team

The research multidisciplinary team comprised two scientists (a breeder and a social economist), village extension officers (VEOs) and enumerators. The team met for a brain-storming session and rapport building before the appraisal. This was done in order to determine what information was necessary and how it could be best obtained. The team went through a checklist of questions prepared for the appraisal and pre-tested the structured questionnaires.

2.1.2 Description of the study area

The study was conducted in Tanga region due to its relative higher potential for rice production than Kilimanjaro region. Two villages were involved i.e. Mkomazi and Mombo villages of Korogwe district (Figure 2.1). Both villages are situated in a vast flood plain that is bordered by the eastern slopes of Pare Mountains to the north – west, and Usambara Mountains to the north - east. Mkomazi village is situated at 04° 39'S and 38° 04'E at an altitude ranging from 396.2 to 457.2 meters above sea level, whereas Mombo village is situated 38°00'E and 4°30'S at an altitude of 338.8 to 402.3 meters above sea level. These sites are within a semi-arid area with annual rainfall of 800-1200mm.

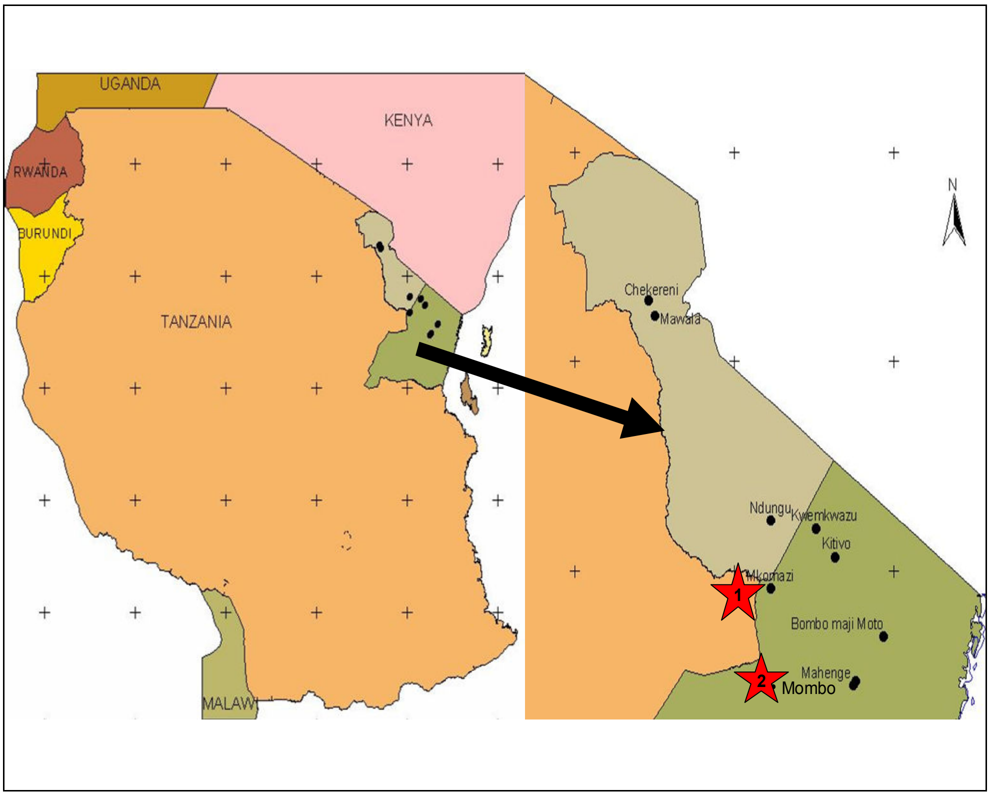

Figure 2.1 Nine irrigation schemes involved in soil characterisation and the two villages of Mkomazi (1) and Mombo (2) for PRA studies.

Most parts of the area are characterized by a weakly bimodal rainfall pattern. Short rain (Vuli) falls from October to December and long rains (Masika) falls from February to May. However, it is currently thought that the area rainfall pattern is changing to uni-modal as the short rains are extremely low. Local experience indicates the onset date and distribution of the rains in both seasons is unreliable and the situation is worsening with time. The mean annual maximum temperature (Tmax) is in the range of 29-31°C and the mean annual minimum temperature (Tmin) is 19-23°C. The mean annual range of temperature is 9°C.

The potential of the area with respect to rice production and reports on salt affected soils in irrigation schemes were major criteria used for selection of these sites. The two villages are representative of the major rice producing areas in the region. In these villages, rice is produced mainly as an irrigated crop and a small portion as lowland rain-fed crop in the form of seasonal flooded bunds in valley bottoms. The villages have rice irrigation schemes which are characterised by different management systems. Mkomazi is a local (traditional) scheme which is characterized by poorly maintained infrastructure whereas Mombo scheme has well maintained and improved irrigation infrastructure.

2.1.3 Data sources

To capture all necessary information, both primary and secondary sources were used. Primary data sources were the district administrative officials, key informants at both district and village levels. Group discussions in PRA, interviews and field observation were the key methods for primary data collection. The main tool in the PRA were probing and brainstorming. The discussion was guided by an open semi-structured questionnaire to probe the farmers on a range of issues related to rice production under irrigated environments and the associated problems with emphasis on problems related to SASs and common varieties used. The PRA techniques applied were trend analysis, seasonal analysis (calendar) and ranking and scoring.

2.1.4 PRA planning and farmers' selection

The village chair person and extension officer helped to organize the meeting with other village leaders and farmers for rapport as well as organizing farmers for interviews. Farmers involved in the informal and formal interviews were randomly selected from the village register by the village and hamlet leaders with the help of the agricultural extension officer. For informal interview, a minimum of 20 farmers, balanced for gender (10 female and 10 males), were actively involved in each village. During the appraisal, the research team leader explained the purpose of the research and the need of selecting study sites. The group of farmers attending the meeting were divided into sub-groups of five people (gender was considered) of which each group addressed one PRA technique (Figure 2.2).

A plenary session was done at the end of group discussions whereby each sub-group presented their findings to all farmers for general discussion.

Selection of interviewees for the formal interview was also based on village household list collected from the village office. Since the majority of villagers in the study area were rice farmers, a list of villagers was provided and the names of every second persons was picked from the list with some adjustments to make sure that women were well represented in the study. Sample sizes of 25 farmers from each village were selected from the list and visited in their homestead for interview.

Figure 2.2 Farmers were divided into groups for focus discussion during the appraisal.

A careful cross section of farmers involved combined traditional and innovative farmers, males and females, full time farmers and farmers with off-farm employment. In this case, the total sample size was 50, which comprised 22 male farmers and 28 female farmers from the two villages. Individual farmers were visited in their homestead and interviewed. This enabled farmers to express their own opinions in a relaxed environment without any influence from the community (Figure 2.3). It also helped the team to learn more on farmer's environment and the type of life.

Individual interviews were done for comparing and/or supplementing the information obtained through PRA methods. The prepared questionnaires were pre-tested and adjusted accordingly. During the interview, practical demonstrations, drawings and observations were frequently used. For instance, farmers were asked to sketch maps of their field on the ground and show the size/portion affected by salts. This enabled the farmer to easily demonstrate and estimate the size of salt affected land area. Field visits were conducted to verify some of the information given during group discussions and individual interviews whereby the research team and volunteer farmers had a walk across several fields for observation.

Figure 2.3 Individual farmer responding to structured questions in a relaxed environment at his home stead.

2.1.5 Data analyses

The data generated from the group discussions, questionnaires and field visit were used for the analysis. Descriptive statistics through frequency means and percentages were calculated for different variables to explore relationships. Statistical analyses of both quantitative and qualitative data were performed in SPSS (Release 15) computer package (SPSS Inc., 2006).

2.2 Results and discussions

2.2.1 Characteristics of Farm Economy

The appraisal exercise involved 18 farmers (62% men and 38% women) at Mkomazi, and 20 farmers (42% men and 58% women) attended at Mombo. During the exercise the team started by exploring the farming system of the study area. Using time lines farmers were able to describe crops grown in their areas for the past 10 years, crops currently grown and abandoned crops as well as reasons (Table 2.1**).**

Table 2.1 Crops grown in the study area for the last 10 years (1995 – 2008).

CROPS/CROPPING ENVIRONMENT	GENDER INVOLVED IN PRODUCTION	YIELD LEVELS			REASON FOR SUCH A TREND
		95-00	01-06	06-08	
RICE/ (IRRIGATED)	BOTH	#######	###	####	- GOOD SOIL FERTILITY, AVAILABILITY OF ENOUGH WATER AND LESS SALT SOIL PROBLEMS IN 1995 –2000. - LESS WATER AND SALT PROBLEMS 2001-2006 - POOR SOIL FERTILITY, SALT PROBLEM, LESS WATER 2006-2008
COTTON/ (RAIN – FED)	MEN	-	##	-	POOR MARKET AND DROUGHT
MAIZE (RAIN – FED)	BOTH	####	###	##	POOR SOIL FERTILITY, INCREASING SALT SOIL , AND DROUGHT
CASSAVA (RAIN – FED)	BOTH	###	##	-	LACK OF ENOUGH LAND, ANIMAL PESTS
- BEANS (RAIN – FED)	WOMEN	-	-	##	AVAILABILITY OF GOOD MARKET
VEGETABLES					
-TOMATOES (IRRIGATED)	MEN	##	#	###	GOOD MARKET AND USE OF CONTROL MEASURE FOR FUNGAL DISEASES
- SWEET PEPPERS (IRRIGATED)	MEN	-	#	###	GOOD MARKET AND USE OF CONTROL MEASURE FOR DISEASES
- COWPEAS (RAIN – FED)	WOMEN	-	-	##	AVAILABILITY OF GOOD MARKET
- WATER MELON (RAIN – FED)	MEN	-	#	#	AVAILABILITY OF GOOD MARKET
- SWEET POTATOES (IRRIGATED)	WOMEN	*	-	-	DROUGHT AND NEMATODE PROBLEMS
- EGGPLANT (IRRIGATED)	BOTH	-	-	#	AVAILABILITY OF GOOD MARKET
- OKRA (IRRIGATED)	WOMEN	-	-	#	AVAILABILITY OF GOOD MARKET

= each represent 10 bags of the product per ha.

A total of 12 crops were mentioned. From the list, three crops (rice, maize and vegetables) were the most commonly grown crops; whereas cotton, cassava and sweet potatoes were the abandoned crops (Table 2.1). Increasing drought, salt development, root and fungal diseases in farmers fields were among the major reasons for abandoning these crops.

Rice and maize were major crops in the area, but their production showed a decreasing trend (Table 2.1). Poor soil fertility, drought and salt soil development were among the reason for such a trend. Vegetables on the other hand, showed an increasing trend due to availability of good markets and proper pest and disease control programme. A short preference – ranking was conducted to assess the group's preference and confirm on the abandonment of the above mentioned crops. The results summarised in Table 2.2 showed that rice was the most preferred crop in the area.

Table 2.2 Rank of crops for preference by farmers in Mkomazi and Mombo

Crop	Mkomazi n=20	Mombo n=20	Mean Rank
Rice	1	1	1
Maize	2	2	2
Beans	4	3	3.5
Vegetables	3	5	4
Cassava	6	6	6
Sweet potatoes	5	4	4.5

Scores: 1 = best and 6 = least preferred crop for the area

A survey of 50 randomly sampled households in the two villages showed that rice and maize were grown by 100% and 75% of households, respectively. The average areas of paddy and maize fields per household were 0.5 and 0.6 ha, respectively, for Mombo and 1.0 and 0.7 ha, respectively, for Mkomazi. Families also grew some minor crops such as cassava and sweet potatoes to suplement their main crops in kitchen gardens. Other crops commonly grown near homesteads were okra and pumpkin. The least preferred crops were cassava and sweet potatoes in Mkomazi, whereas, in Mombo, cassava and vegetables were the least preferred crops. Mean ranking of crop preference for the two villages also showed a similar trend.

The study also revealed that rice and maize were major staple foods in both villages and the main staple foods for lunch and supper, respectively. The food preference patterns were similar in both villages. Figure 2.4 summarised the frequency of materials used as staple foods for meals in each month whereby rice dominates both meals especially during supper. According to the Tanga Regional Development Report (1992), rice consumption was high in the region and has been increasing in recent years. However, storage of rice grains to sustain most of the families throughout the year was difficult for most of the farmers.

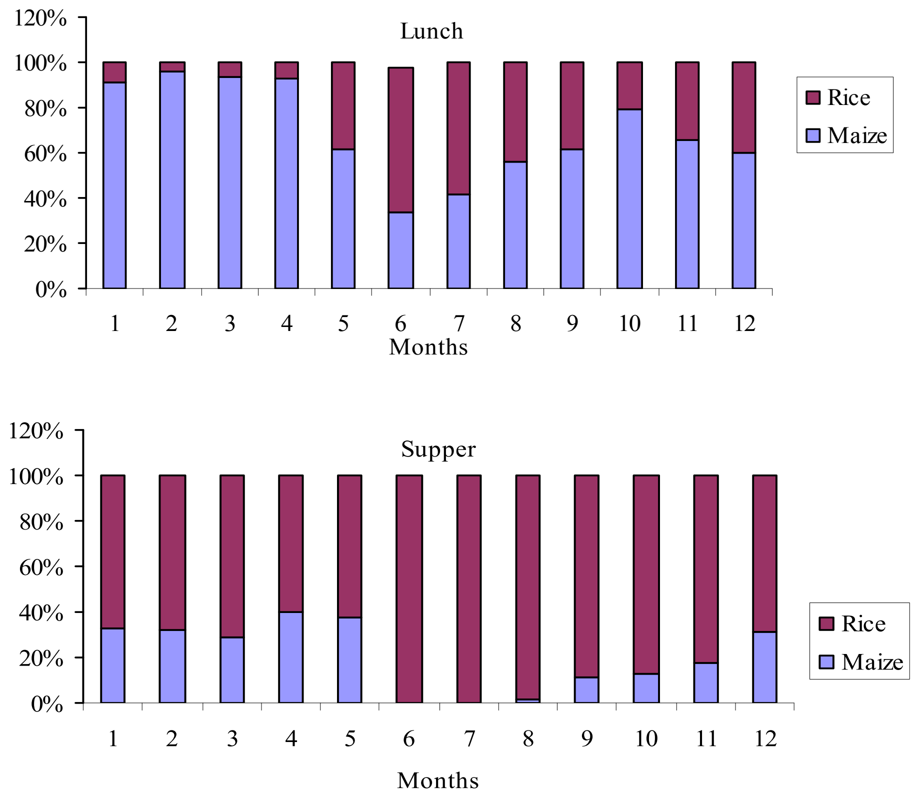

Figure 2.45Usage frequencies of staple foods for meals: *(1=January to 12=December)*

This was exposed during the household survey whereby, only 7% and 3% of respondents in Mombo and Mkomazi, respectively, stored their rice harvest to sustain themselves throughout the year and the majority 60% and 53% in Mombo and Mkomazi, respectively, stored their food supply for only 4 months after harvest and then purchased most of their other food materials. Generally, families were forced to sell their rice crops immediately after harvests when prices were very low as they needed cash for daily necessities such as school and medical fees, ceremonial occasions or paying back the loans they incurred for field operations. The study therefore established that rice was a significant and most preferred crop in the area, and it was used for both cash and food in almost all households in the study area.

2.2.2 Descriptive statistics of household characteristics

2.2.2.1 Gender involvement in farm activities and education level

These survey results, visual observations and information from key farmers and government officials indicated that more female farmers were involved in farm activities than men in the study area. The informal interview in both villages also revealed that more women participated in rice cultivation compared to men. Results from formal interview similarly indicated that women participation in rice farming was also higher in individual villages with 26 and 30% females in Mkomazi and Mombo as compared to 24 and 20% males, respectively, in the two villages (Table 2.3).

It has also been observed more in Mkomazi than in Mombo that the number of females in the under-20 age group was far less than expected although the difference disappeared in older age groups, presumably as males take wives from outside the village. Most of the juvenile females are commonly migrating to neighbouring town to look for jobs and also preferred to get married far from the area. It is likely that the high numbers of juvenile females “missing” are due to acute poverty in the salt-affected community. Similar findings have been reported by Ijaz and Davidson (1997) in salt affected Punjub community in Pakistan where juvenile females were far less than other age groups and the reasons were also associated with the acute poverty in the salt affected communities.

Results showed that men prefer to involve themselves in business and other off - farm activities and either assigning their wives to farm activities or wives opted to undertake farm activities to keep themselves busy and avoiding over-dependence on their husbands. A similar finding on more females’ involvement in farm activities than men has been reported by Kruger (2006), Mergeai *et al*. (2001) and Ijaz and Davidson (1997). Females on the other hand, do prefer small business but lack of capital is a great hindrance for their involvement.

The study also showed that men, especially the youth generally preferred less difficult and fast money earning jobs. So they tended to shift to nearby busy townships for small hand carrying businesses. This was observed to be more critical in Mombo village where only 8% of young ages engaged in farm work as compared to 24% of the same age group from Mkomazi village. The presence of a big bus stop in Mombo where most of the country buses stop for lunch forces Mombo youth to run for fast food and fruit businesses leaving only middle age group (26%) and old age group (14%) to work on the farms. Mkomazi village was not very active in business which was why young people (24%) engaged more on farm work compared to middle age group (12%) and old age group (14%) (Table 2.3).

Thus, a major challenge of institutional breeding programme is to figure out ways to foster increased participation by the end users. Unfortunately, however, most research projects which claim to practice 'participatory research' aimed at poverty alleviation do not automatically result in participation or inclusion of the marginalized groups of the society, especially poor rural women (Paris *et al*., 2008). The study revealed that women's actively involved themselves in rice production, post-harvest and seed management, therefore agricultural scientists and extension workers should consider consulting women farmers or include them in farmer-managed trials. Ignoring women's indigenous knowledge and preferences for rice varieties may lead to slow adoption of new varieties.

Education refers to formal schooling attained by the respondent in the study area. Three education level groups can be distinguished, these are, no formal education, primary education (4 to 8 years of primary school) and secondary education (4 years of secondary school education). About 82% of the total respondents had primary school education, only 6% had attained secondary education and the rest (12%) had no formal education (Table 2.3). This indicated that the majority of farmers in the area could read and write which also suggested that the community could understand and handle their problems when awareness programmes were in place.

Mombo village had more people who had attained primary education (46%) and less number of people with no formal education (2%) whereas only 36% had attained primary education and 10% had no formal education in Mkomazi village. The majority of respondents with no formal education and school drop-outs were females. The results further revealed a significant negative correlation ($r = -0.72$; $p<0.01$) between education level of respondents and the incidences of salt affected soils in farmers' fields. Similarly, a positive correlation ($r = 0.69$; $p<0.01$) was also found between their farmers' knowledge/awareness on salt soil problem and their effect. This indicated that farmers in more salt affected communities had less education and is less aware of the problems and the threats to rice production.

Table 2.3 Household characteristic of respondents in the two villages of Tanga region

Characteristics	Variable	Respondents by Village (%)		Total (%)
		Mkomazi n-25	Mombo n=25	
Gender	Male	24	20	44
	Female	26	30	56
Education level	Non schooling	10	2	12
	Primary	36	46	82
	Secondary	4	2	6

Ijaz and Davidson (1997) compared salt-affected and control areas in the Pakistan Punjab. They also found that 91% of women in salt affected areas were illiterate, compared with 71% in non- salt affected areas, and that only 15% of males in the salt affected areas were educated beyond matriculation, compared with 30% in the control area. The overall level of human development, especially among women, was far lower in salt soil affected than in non-salt soil affected communities. Demeke (2003) concluded that exposure to education can increase the farmers' management capacity and reflect a better understanding of the benefits and constraints of soil conservation. Also, education increases the capacity and ability to obtain and apply relevant information concerning the use of soil conservation practices (Cools *et al*., 2003). Therefore the study recommends that women farmers should be provided with knowledge and skills in proper management and conserving the soil and seeds, as well as in managing crops and other farm resources. Women can play key roles as change agents if they are provided with access to varieties suited to their needs, and they will disseminate improved quality technology to other farmers.

2.2.2.2 Respondent's major economic activities

The appraisal exercise revealed that subsistence farming was a major economic activity of respondents in the study area. Formal survey results verified this by showing that about 64% of respondents' occupations were pure crop cultivation, followed by a combination of crop cultivation + livestock keeping (28%), crop cultivation + informal sector employment (6%) and crop cultivation + formal sector employment (2%). Results also revealed that Mkomazi village had more of pure subsistence farmers (36%) and less-off farm activities than Mombo village where only 28% farmers practiced pure crop cultivation.

This was due to the fact that Mombo is located in a more advantageous site for off - farm activities than Mkomazi. For example, lots of fruits are produced in Lushoto district and transported to Dar – es – salaam (DSM), Tanga, Kilimanjaro and Arusha through Mombo town. The DSM-Moshi - Arusha major road and the Mombo-Lushoto road are important routes for haulage of inputs and produce for the scheme. A railway line that runs alongside a major road through Mombo is part of the Tanzania railway network. The line is a potential route for transportation of goods. Thus, in Mombo village, both locality and availability of off-farm activities and opportunities increases money circulation which also contributed to cash availability to sustain rice farming compared to Mkomazi village.

This was reflected by the survey results on major farmers' sources of income in both villages. When farmers were asked if they had other sources of income other than agriculture, the results were 65.5% for Mombo and 31.8% for Mkomazi. However, 34.5% and 60.2% of Mombo and Mkomazi farmers, respectively, had no other sources of off-farm income. The analysis of the availability of remittances also agreed with these findings and showed that there were more Mombo respondents (59%) who had access to remittances from relatives and from other areas than Mkomazi respondents (17%); it could be assumed that this bolsters their (Mombo respondents) financial status and have influenced positively in rice production investments and soil conservation in salt affected fields.

Gould *et al.* (1989) in the USA reported that increasing involvement in off-farm employment for income generation seems to reduce the incentive for land conservation. The report went further that probability of adoption of indigenous soil conservation practices in semi-arid areas increased with increasing farmer involvement in off-farm employment. The study therefore found that although the majority of farmers in the area involve themselves largely in rice cultivation. There was the fact that income generated through off-farm involvement eased the liquidity constraint for farm operations and soil conservation investments or purchase of fertility enhancing inputs.

2.2.2.3 Income level groups and annual Income contribution

Three income levels (very low, low and medium) were identified based on farmers' criteria. The criteria used included type of house and assets owned; involvement on well paying off-farm activities and amount of rice harvests per year/season. The majority of farmers (52%) fell under the low income group followed by medium (34%) and only 14% fell under the very low income group. However, the situation was different in individual villages whereby Mombo village had more medium income grouped farmers (26%) and very few (4%) fell under very low income group. In Mkomazi, the majority (32%) fell under the low income group and 10% fell under the very low income group. Results also showed a positive correlation ($r = 0.45$; $p<0.01$) between salt affected fields and the low income group. The study therefore shows that the overall level of human development and income generation especially among farmers were lower in more salt affected communities. Hollington (1998) has also reported the low level of income generation in the salt affected than non-affected areas.

In this case Mombo farmers were economically better-off compared to farmers in Mkomazi. This was also reflected by the type of houses owned by farmers in the two villages whereby 8% of Mkomazi farmers owned houses made of bricks and iron sheets, 34% had houses made of iron sheets and mud and 8% had thatched and mud made houses. On the other hand, 26% of Mombo farmers had brick and iron sheets houses, 24% had mud and iron sheet houses and only 4% had thatched and mud houses. Ninety-eight percent of the total respondents claimed that rice was a major annual income contributor in their families; it contributed more than 50% of their annual income. On the other hand, about 64% of respondents claimed that maize contributed very little (less than 10 %) of their annual income (Figure 2.5). This was also the case in individual villages whereby 45% and 44% of respondents in Mombo and Mkomazi villages, respectively, claimed that rice contributed more than 50% of their annual income, where as 5% and 6% of respondents in Mombo and Mkomazi, respectively, said it contributed between 40 – 50% of their annual income. These finding indicate that rice is the major source of income in Korogwe district, Tanga region; it contributed more than 50% of annual income to the majority of farmers under rice based farming systems.

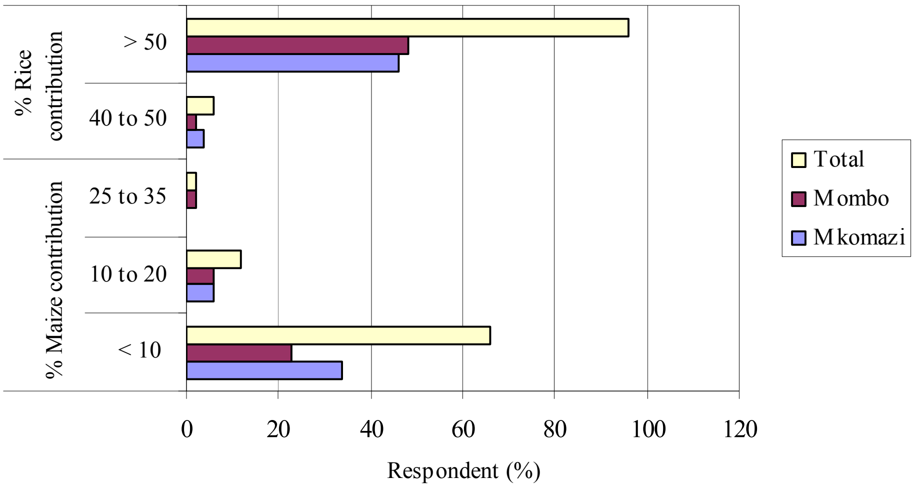

Figure 2.5 Major annual income contributors in Mkomazi and Mombo villages (n=50)

2.2.3 Rice cultivation

Rice production in the north-eastern Tanzania is done mainly in irrigated schemes located in inland valleys which are also located on wide river floodplains (Figure 2.6). Each inland valley represents a toposequence of a valley bottom with its hydromorphic edges, and the contiguous dryland slopes where most of the farmers occupy small plots mainly for maize cultivation. These kind of inland valleys are known as *vitivo* in Tanzania, *dambos* or *boliland* in most of other eastern and central African countries. Few well managed irrigation schemes with well constructed infrastructure do exist but small local irrigation schemes are characterised by poor infrastructure in the area.

Figure 2.6 Mkomazi small scale rice fields with poor management and local water distribution infrastructures *(left)*, compared to a well maintained field in Mombo irrigation scheme *(right)* (September, 2008)

The two villages (Mkomazi and Mombo) contribute significantly to rice production at both district and regional level. However, a decreasing rice production trend for the past ten years has been observed (Table 3.1). The trend was also confirmed by the district rice production data (Figure 3.8) which also showed a continual decrease with a decrease in rainfall (Tanga Regional Development report, 2008). At village level, rice production was very low, but differed significantly between villages. Farmers reported the average yield in the two villages was estimated to be 1.8 t ha^{-1} (range 0.8 to 2.5 tha^{-1}). The average yields for 13 years indicated that rive yield in both villages ranged between 0.8 to 1.6 tha^{-1}. Mombo showed relatively higher yields than Mkomazi village (Figure 2.7). According to the scheme leaders and key informants, differences in scheme characteristics (Table 2.4) were the main reasons for yield differences in these villages.

Mombo farmers reported that, higher yields in 2001 were due to completion of irrigation infrastructure at the scheme. However, two major constraints causing decreasing production trend thereafter were identified. The first constraint was inadequate availability of the irrigation water. This was a consequence of a decline in amount and poor distribution of rainfall in the Usambara and Pare mountain area during recent years.

The decline in rainfall has been a major cause of low base flow in rivers which supply water to the irrigation schemes. Low base flow was also contributed by water competition between vegetable growers in upstream and rice growers down stream. A similar finding on water competition between upstream and down-stream growers in Mombo village has also being reported (Ley, 2004).

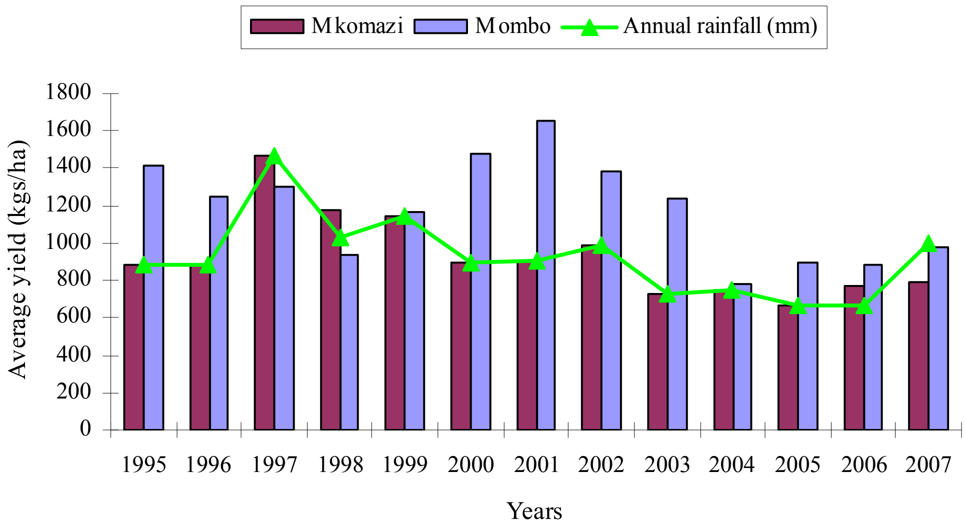

Figure 2.7 Annual rainfall and rice yield trend in Korogwe district.

The second major constraint was salt build-up in the soils of the schemes. Soil salinity and sodicity was reported to be intensifying. The majority of farmers believed that salts originate from the soil itself. During irrigation standing water in the fields probably brings up salts from the deeper subsoil to the topsoil. They also believed that repeated cycles of irrigation and inadequate drainage as well as movement of irrigation water from one field to another were probably the major causes for the spread of salt affected soils in the scheme. Survey results also indicated the low yields where by the majority (about 20%) of farmers harvested between 11 to 25 bags of 70kg capacity (0.7 – 1.8tons) in their average 0.6 ha, and very few (<5%) harvest more than 55 bags (3.8tons) from the same farm size. Yield levels showed to be higher in Mombo than in Mkomazi (Figure 2.8) as mentioned earlier.

Table 2.4 Major characteristics of Mkomazi and Mombo irrigation schemes

CHARACTERISTICS	MKOMAZI SCHEME	MOMBO SCHEME
STATUS	LOCAL SCHEME	IMPROVED SCHEME
ORIGIN OF FARMERS (NO. OF VILLAGES)	7	4
TECHNICAL & SOCIAL COHESION	WEAK	STRONG
DOMINANT CROPPING SYSTEMS IN A YEAR	RICE – MAIZE/LEGUME/VEGETABLES ROTATION	RICE – RICE ROTATION
AVERAGE RICE FARM SIZE PER FARMER	0.75HA	0.5 ACRE
LAND PREPARATION	MANUAL	CULTIVATOR
WATER SOURCE	FLOODING	GRAVITY IRRIGATION
IRRIGATION INFRASTRUCTURE	NONE	AVAILABLE
WATER RESERVOIR	NONE	AVAILABLE
AVAILABILITY OF BUNDS	PARTIAL	OVERALL
RISKS OF FLOODS/DROUGHT SEASONS	HIGH	MODERATE
FERTILIZER USE	NONE	UREA
USE OF IMPROVED SEED	HIGH	HIGH
ACCESS TO AGRICULTURE INFORMATION	VERY LOW	HIGH

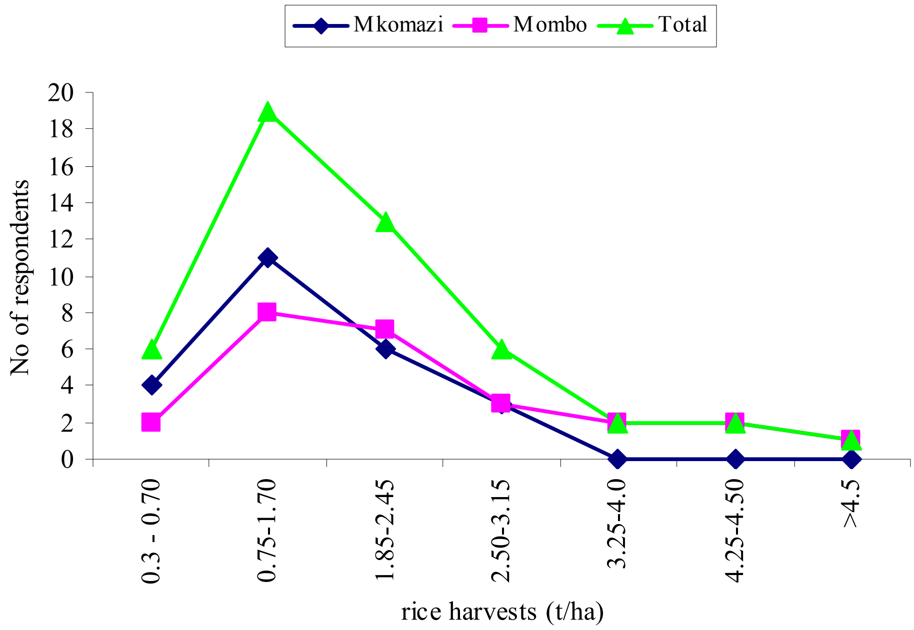

Figure 2.8 Rice harvest per season in Mkomazi and Mombo villages (n=50)

2.2.4 Rice production constraints

During the appraisal the following production constraints were identified in both villages; salt affected soils, seasonal drought and floods, birds, expensive inputs, lack of capital, insects, poor water control, poorly levelled fields and diseases. When farmers in each village were asked to rank these constraints the results were different between the two villages. Farmers in Mkomazi ranked salt affected soils followed by drought (Table 2.5a) as major constraints in their area whereas, at Mombo, farmers identified drought followed by salt affected soils as most important constraints (Table 2.5b). Insect pests and diseases were ranked the least as a problem in Mkomazi and the problem didn't come out clearly as a constraint in Mombo village.

Table 2.5a Pair - wise ranking of rice production constraints in Mkomazi village

	Drought	Lack of capital	Birds	Insects/ Diseases	Salty soils	Poor extension services	Total
Expensive inputs	Inputs	Capital	Inputs	Inputs	Salts	Both	4 (3)
Drought		Drought	Drought	Drought	Both	Drought	5 (2)
Lack of Capital			Capital	Capital	Salts	Extension	3 (4)
Birds				Birds	Both	Birds	3 (4)
Insects/ Diseases					Salts	Insects/ Diseases	1 (6)
Salty soils						Salts	6 (1)
Poor extension services							2 (5)

- Both means the two constraints are equally important
- Number in parenthesis is a rank for specific problem.

Table 2.5b Pair - wise ranking of rice production constraints in Mombo Village

	Salt affected soils	Birds	Expensive inputs	Lack of farm implements	Total
Lack of enough water	Both	Water	Water	Water	4 (1)
Salt affected soils		Birds	Salts	Salts	3 (2)
Birds			Inputs	Birds	2 (3)
Expensive inputs				Inputs	2 (4)
Lack of farm implements					0(5)

- Both means the two constraints are equally important
- Number in parenthesis is a rank for specific problem.

The overall results from formal survey also indicated that salt affected soils and drought were the most important constraints. About 72% of total respondents claimed to have been seriously affected by the problems (Table 2.6). De Pauw (1984) reported that these soils were common mainly in the lowlands of alluvial plain and Pangani river valleys which lie on the volcanic lava and ashes of Kilimanjaro and Meru mountains and eastern part of the country. The study results imply that the significant yield gap could be attributed to some of the factors listed in Table 2.6. This emphasized the importance of developing new varieties that are salt and drought tolerant, high yielding and adaptable to farmers' needs.

Table 2.6 Major Rice production constraints in Mkomazi and Mombo villages

Constraints	% Respondents Mkomazi (n=25)	Mombo (n=25)	%Total (n=50)
Salt Affected Soils	34	38	72
Seasonal Drought & Floods	34	26	60
Birds	20	18	38
Expensive Inputs	16	18	34
Lack of Capital	20	12	32
Insects	6	26	32
Poor water control	20	2	22
Poor levelled fields	10	6	16
Diseases	0	4	4

2.2.5 Farmers' perceptions on salt affected soils

During the appraisal farmers showed good understanding on the effects of salt affected soils in their fields and water sources. Generally, plants growing in these soils and visual soil characteristics sometimes give clues about the problem. The following local indicators are mostly used by farmers to characterise their fields: stunted plants, yellow striped plants on middle to upper leaves as a sign of high soil pH (indicating zinc and iron deficiency), whitish top soils with salty taste, patches of bare land, growth of *Kuruwira or minywanywa* plants (salt bushes), salty taste sugarcane, blackish soils, water logging not caused by rising water table. Indicators for salty water are salty taste water, dry skin after bathing, using lot of soap when washing clothes.

Farmers listed the commonly used indicators and ranked them (Table 2.7). All the listed indicators were ranked equally in both villages. Crop performance and yield were important indicators used by farmers, having been ranked number 1 and 2, respectively. Other indicators were soil colour, presence of specific indicator plant species, soil compactness (soil tilth) and visible salts on soil surfaces. The relative importance of indicators was similar in both villages.

Table 2.7 Ranking and scoring of salty soil indicators by farmers in Mkomazi and Mombo villages

	TOTAL SCORE		MEAN SCORES		RANK	
INDICATORS	**MKOMAZI**	**MOMBO**	**MKOMAZI**	**MOMBO**	**MKOMAZI**	**MOMBO**
STUNTED GROWTH &LEAF BURN	**19**	**20**	**6**	**6**	**1**	**1**
POOR CROP YIELD	**16**	**18**	**5**	**5**	**2**	**2**
SOIL COLOUR	**13**	**16**	**4**	**5**	**3**	**3**
INDICATOR SPECIES	**10**	**12**	**3**	**3**	**4**	**4**
SOIL TILTH	**8**	**11**	**2**	**3**	**5**	**5**
SALT ON SOIL SURFACE	**8**	**10**	**2**	**3**	**6**	**6**

Scoring of indicators was based on a ranking scale from1-6, with 1 as the least important to 6 as the most important (n=50)

When the individual farmers were asked about the sources of salty soils in their field, only few (4% and 16% in Mombo and Mkomazi, respectively) could not explain. The rest were aware and had different perceptions on the actual source of salt problems in the soil. A large group (34% and 70% in Mombo and Mkomazi, respectively,) claimed that it was nature of the soils in their field, 28% and 8%, respectively, thought that it came naturally from sub soils when water table is low and evaporation is high, 14% and 16%, respectively, attributed the problem to salts movement from one field to another through irrigation water and 8% and 2%, respectively, claimed that irregular use of chemical fertilizer might be the reason for salt accumulation in the fields (Figure 2.9). These results indicate that farmers' are aware of the problem; however, Mombo had higher awareness level that Mkomazi. Therefore indicate further that the use of salt tolent varieties can easly adapted in these areas.

Although no significant difference was found on the perception of the causes of salt affected soils among farmers in the two villages, their perception of its severity was observed to be different. Figure 2.10 shows that 30% and 20% of farmers in Mkomazi and Mombo, respectively, regarded the severity of salt affected soil as "very bad" category, whereas, the majority of farmers regarded the severity to be on the "bad" category. Mombo farmers were generally found to be more aware of the severity of the process of SAS and its impact in their areas and it seemed this level of awareness influenced positively their management decisions.

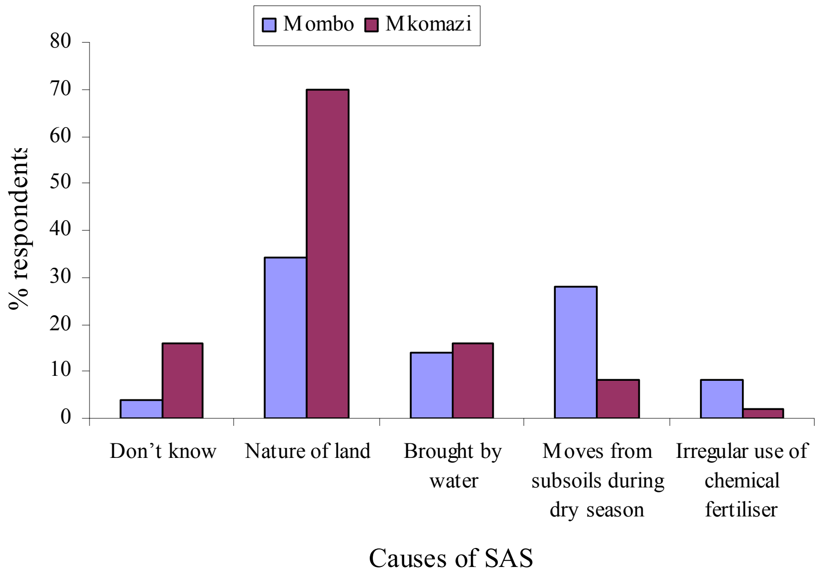

Figure 2.9 Percentage respondent on major causes of salt problems in the soil (n=50).

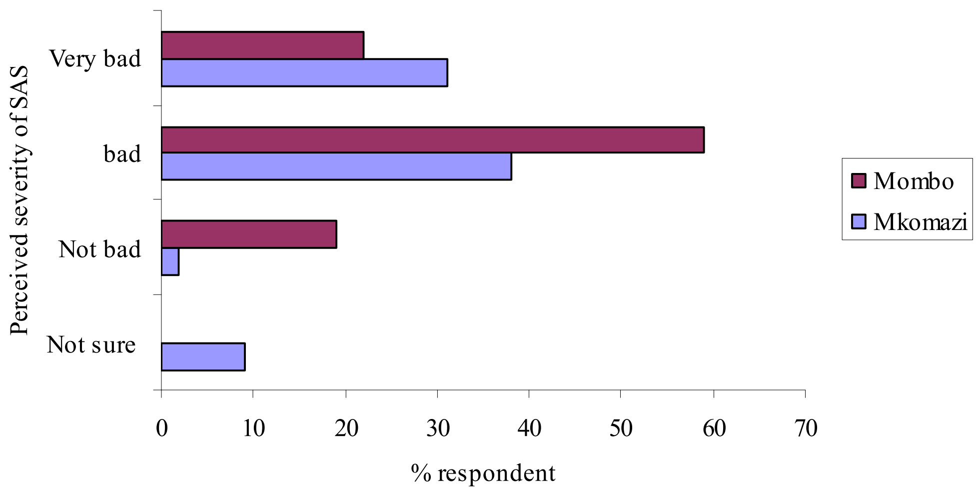

Figure 2.10 Salt affected soil status and farmers perception (n=50).

Farmers' perception of SASs and recognizing it as a problem is an important factor that influences the application of controlling practices. Kruger (2006) and Wickama *et al.* (2006) added that farmers' perceptions could be a good entry point for any intervention on the environmental conservation either by changing their perception through demonstrations or building on what they already know. The perception of problem and technology attributes by the farmer plays a very important role on whether or not the technology is adopted (Gould *et al.*, 1989).

2.2.6 Rice cultivars preferences

Rice cultivars used by most of the farmers in the North Eastern Tanzania belong to the *indica* sub-species of *Oryza sativa.* A wide range of these has been obtained from other places in and outside the country. Most of them have medium plant stature, photoperiod insensitive, and are early to medium maturing. It was stated during the appraisal that farmers always experimented with new varieties and selected those which meet their preferences and that were suitable under the local circumstances such as soils. However, some of the farmers preferred planting more than one variety to match with unexpected local environmental changes and/or to have a small portion of the field planted with aromatic variety specifically for their own food. This is also common practice to most rice farmers elsewhere (Tesfai *et al.,* 2002).

The farmers were asked to list all the preferred varieties and to indicate the potential attributes of each variety. Eight varieties were listed and the specific reasons for their preferences were established (Figure 2.11 and Table 2.8). Mkomazi farmers showed to have a wider range of variety preferences than Mombo farmers. When farmers were asked to rank the varieties according to their preferences, pairwise ranking results showed differences in ranking of cultivar preferences between villages (Table 2.9). The results also showed the varieties preferred in Mombo are not preffered in Mkomazi. Mainly two varieties (IR 64 and TXD 306) are highly preffered in Mombo where as IR 56 followed by IR 54 was ranked high in Mkomazi. Farmes in Mkomazi preferred IR 56 and IR 54 over TXD 306 and IR 64 due to their tolerance to water fluction and harsh environment.

On the other hand farmers in Mombo prefered IR 64 due to it high tillering ability and high yields and TXD 306 is preffered due to high yield, good cooking and grain qualities as well as aroma. However, farmers pointed out that for good yield, TXD 306 needs lot and constant water supply (Table 2.8). This therefore indicated that farmer differed in their preferences to specific varieties.

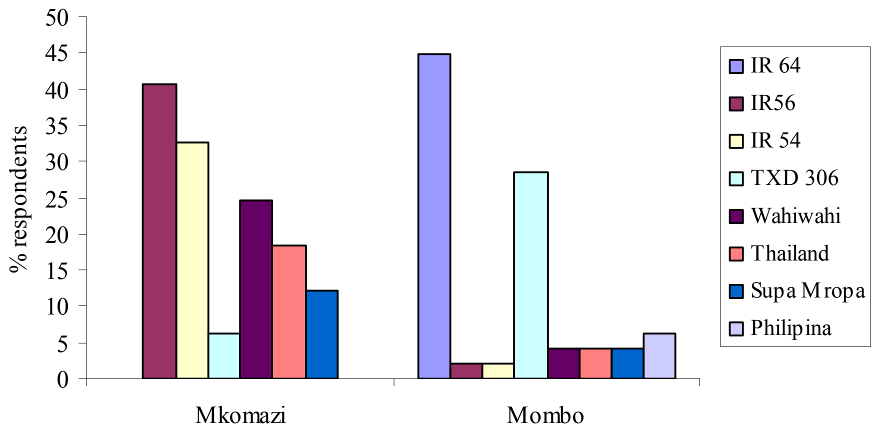

Figure 2.11 Major cultivated varieties in the study areas (n=50)

Table 2.8 Traits for major cultivated varieties in Mkomazi and Mombo villages

MKOMAZI VARIETIES	**CHARACTERISTICS**
IR 56	**MEDIUM HEIGHT, MEDIUM MATURING, DROUGHT TOLERANT, HIGH YIELD, GOOD MARKET, SWELL DURING COOKING BUT POOR TASTE (MAINLY FOR MARKETING)**
IR 54	**MEDIUM HEIGHT, MEDIUM MATURING DROUGHT TOLERANT, HIGH YIELD, GOOD MARKET, SWELL DURING COOKING BUT POOR TASTE (MAINLY FOR MARKETING)**
THAILAND	**MEDIUM HEIGHT , GOOD TASTE, GOOD MARKET AND MILLING QUALITY, GOOD YIELD**
KAHOGO	**GOOD TASTE, AROMA AND MILLING QUALITY BUT SUSCEPTIBLE TO HARSH ENVIRONMENT**
WAHIWAHI	**VERY EARLY MATURITY, POOR TASTE, POOR MARKET AND SUSCEPTIBLE TO HARSH ENVIRONMENT**
TXD 306 (SARRO 5)	**HIGH YIELD, GOOD TASTE AND MILLING QUALITY, SLIGHTLY LATE MATURING TOLERANT**
MOMBO VARIETIES	**CHARACTERISTICS**
IR 64	**MEDIUM HEIGHT, HIGH YIELD, SLIGHTLY TOLERANT TO DROUGHT AND DISEASES (MAINLY FOR MARKETING)**
TXD 306 (SARRO 5)	**HIGH YIELD, MEDIUM HEIGHT, GOOD COOKING QUALITIES (TASTE AND AROMA)**
WAHIWAHI	**EARLINESS**
THAILAND	**GOOD TASTE, GOOD MARKET AND MILLING QUALITY, GOOD YIELD**

These results were confirmed during survey study that IR 64 is cultivated by majority (45%) of farmers followed by TXD 306 (Sarro) which was cultivated by 28% of the farmers and very minimum numbers of farmers cultivated IR 56 and IR 54 in Mombo area. On the other hand IR 56 followed by IR 54 were the major varieties cultivated by 42% and 36% of respondents respectively in Mkomazi village, very few farmers (7%) cultivate TXD 306 in the village. The results indicated further that the improved varieties (IR 64, IR56, IR54, TXD 306, Thailand) were more preferred over varieties than local landraces (Wahiwahi, Supa-mropa and Philipina). However, farmers in Mombo village use more improved varieties which resulted in higher production than Mkomazi village.

Table 2.9 Pair - wise ranking of varieties preferred by farmers

VARIETY PREFERRED BY FARMERS IN MKOMAZI						
	IR 56	**THAILAND**	**KAHOGO**	**WAHIWAHI**	**TXD 306**	**TOTAL**
IR 54	**BOTH**	**IR 54**	**IR 54**	**IR 54**	**IR 54**	**5**
IR 56		**IR 56**	**IR 56**	**IR 56**	**IR 56**	**5**
THAILAND			**KAHOGO**	**THAILAND**	**THAILAND**	**2**
KAHOGO				**WAHIWAHI**	**TXD 306**	**1**
WAHIWAHI					**WAHIWAHI**	**2**
TXD 306						**1**
VARIETIES PREFERRED BY FARMERS IN MOMBO						
			TXD 306	**THAILAND**	**WAHIWAHI**	**TOTAL**
IR 64			**IR 64**	**IR 64**	**IR 64**	**3**
TXD 306				**TXD 306**	**TXD 306**	**2**
THAILAND					**THAILAND**	**1**
WAHIWAHI						**0**

2.2.7 Varietal traits preferred by farmers

High yielding, earliness and aroma were the three major traits that were emphasized by all respondents interviewed in the study area (Figure 2.12). The rest of the traits included long and compact panicles, high tillering, and medium height and strong culms with 58%, 66% and 60% of respondents, respectively. Aromas, less sticky and swelling were the major preferred grain cooking qualities with 65%, 57% and 48% of respondents, respectively. About 70% of the respondents in Mombo and 76% from Mkomazi were of the opinion that major varieties grown in both villages were non-aromatic. These varieties were however high yielding and slightly tolerant to harsh environment (water stress and salt tolerant). A number of varieties have been abandoned due to the fact that they lack the specific qualities (Table 2.10) preferred by farmers.

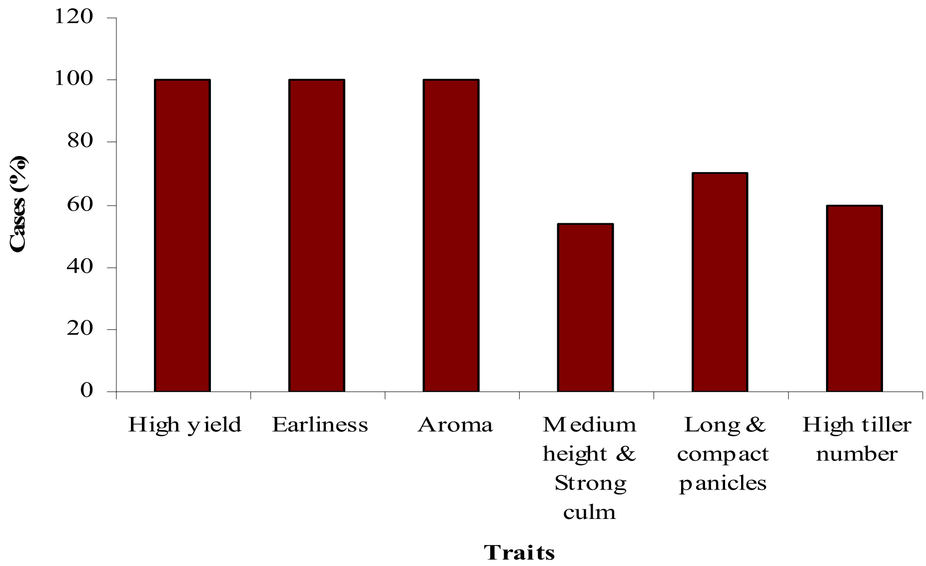

Figure 2.12 Rice traits preferred by farmers in Mkomazi and Mombo villages (n=50)

Table 2.10 Major abandoned varieties and major reasons for their abandonment

ABANDONED VARIETY	% RESPONDENTS		TOTAL (N=50)	MAJOR REASONS FOR ABANDONING
	MKOMAZI (N=25)	MOMBO (N=25)		
SUPA-MROPA	**21.4%**	**14.3%**	**35.7%**	**- VERY LATE MATURITY**
SHINGO YA MWALI	**2.4%**	**4.8%**	**7.1%**	**- LATE MATURITY**
WAHIWAHI	**19.0%**	**21.4%**	**40.5%**	**- POOR YIELD, LOGGING - SUSCEPTIBLE TO DROUGHT**
THAILAND	**2.4%**	**4.8%**	**7.1%**	**-LATE MATURITY, POOR YIELD**
TXD 85	**0%**	**4.8%**	**4.8%**	**- POOR COOKING QUALITY - DIFFICULTY TO THRESH - POOR YIELD**
TXD 40	**0%**	**2.4%**	**2.4%**	**- POOR COOKING QUALITY**
AFAA MWANZA	**0%**	**19.0%**	**19.0%**	**- VERY POOR COOKING QUALITY**
MOSHI WA SIGARA	**7.1%**	**2.4%**	**9.5%**	**- LOW YIELD, LATE MATURITY**
MAGANDA MANNE	**11.9%**	**.0%**	**11.9%**	**- LOW YIELD - LATE MATURITY**
KIFUMBA	**4.8%**	**.0%**	**4.8%**	**- LOW YIELD - LATE MATURITY**
TOTAL	**42.9%**	**57.1%**	**100.0%**	

Poor yield, cooking qualities, logding and late maturity are the major reasons for abandonment of some of the varieties. A list of abandoned varieties was made (Table 2.10) and results indicated that Wahiwahi (means the earliness) - a local early maturing variety and Supa/Mropa – a local highly aromatic variety were abandoned by the majority of farmers. Despite its earliness trait, about 40% of respondents abandoned Wahiwahi due to lodging and poor yield characteristics. More than 37% of respondents abandoned a local variety, Supa, due to its very late maturing characteristics despite its aroma and good cooking quality. This calls for a necessity of understanding farmers' trait preferences foe cultivar development. Varieties which do not have preferred qualities can be easly abandoned by farmers.

Results indicated that farmers, especially in Mombo and Mkomazi, preferred a cultivar that would combine high yield potential, early maturity and aroma. However, yield potential and earliness were the main reasons why the the majority farmers' grew IR 64, IR 56, and IR 54. The results therefore implied that these trait preferences should be highly considered during development of salt tolerant rice cultivars for these areas. Variety TXD 306 showed also to have good grain yield qualities despite its late maturity, therefore incorporating genes for earliness and salt tolerance would increase the potential of this cultivar in the area.

2.2.8 Use of improved agriculture practices

The majority of farmers in Mombo used improved farm management practises and 50% of respondents' accessed agriculture information (48% accesses through extension officer and 2% through innovative farmers). This was also reflected by the fact that farmers with SAS fields used control measures to minimize the effect of salt in their rice fields (Figure 2.13), whereas none of Mkomazi farmers used salt management practices. A relatively high awareness level on the impact and severity of SASs by Mombo than Mkomazi farmers' may have influenced their decisions to practice control measures. Fashola *et al.* (2007) and Gould *et al.* (1989) commented that the higher level of awareness of the severity of land degradation problem may have influenced their decisions to adopt and sustain the use of the introduced measures.

Major control practices employed by Mombo farmers were the use of different local amendments such as incorporation of ash from rice husks, farm yard manure (FYM) and gypsum, flooding and empting their fields several times before transplanting, use of tolerant varieties or changing to new varieties (Figure 2.13). Field flooding and use of FYM were common control practices for salt affected fields in Mombo village as a result, yield in these fields were higher than those at Mkomazi. About 20% of respondents harvested 0.3-0.7 t, 26% harvested 0.7-1.4 t and 2% got yields as higher as > 1.4 tha^{-1} in an average of one acre of affected rice fields.

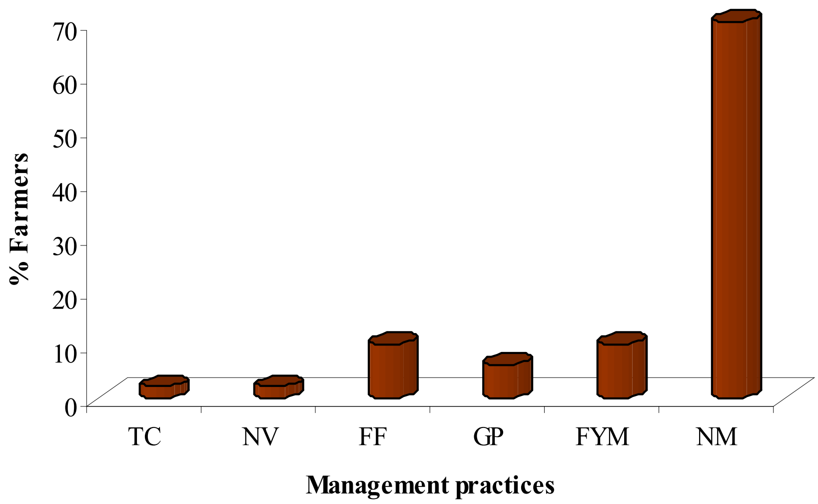

Figure 2.13 Use of salt management practices in Mombo irrigation scheme (n=50)
TC= Use of tolerant cultivar, NV=Change to new variety, FF=Flush floods, GP=Use gypsum, FYM=Use of farm yard manure, NM = No control Mechanism used.

2.2.8.1 Access to extension services.

When asked to evaluate their access to extension services in both villages, the survey results indicated that it was high in Mombo scheme where 85% of respondents had access to agriculture information and very low in Mkomazi where only 8% had access to agriculture information. About 40 % of respondents from Mkomazi were of the opinion that it was average indicating that they possibly had more access to it. However, the majority, about 43 %, regarded it as very poor. The study has revealed that traditionally, weak communication structures in technology development and transfer existed in Mkomazi area. The policy to base extension programmes on diagnostic surveys and top-down approaches that lead to the promotion of 'blanket' extension recommendations to farmers in very different physical environments have been brought up during the appraisal.

Furthermore, only 14% of farmers in Mkomazi access agriculture information, whereby 12% access information through innovative farmers and 2% through radio. The majority (36%) had no access to any agriculture information. All these have contributed to relatively low yields whereby 32% of respondents reported to harvest between 6 to10 bags of rice, 10% harvests 0-5bags and only 6% harvest 11 to 20 bags in an average of one acre of affected rice fields. Fashola *et al.* (2007) highlighted the involvement of media as means to speed up technology transfer among farmers where the new varieties information was broadcast.

2.2.8.2 Local seed system

Results indicated that 96% of farming households in Mkomazi and Mombo villages were dependent upon informal seed sources. Seed flow occurred through farmers' social networks. These communities managed their rich rice diversity through bartering, gifts, borrowing seed or seedlings, and purchases. The absence of well formulated seed delivery system increases the use of mixed and unimproved varieties. This has also been reported by Fashola *et al.* (2007). Research institutions should provide appropriate and location-specific technological packages. The extension services should ensure farmers use correctly and systematically recommended technical packages. A farmer's ability to adopt those technologies depends on the linkages among research institutions, extension services and farmers.

2.3 Conclusion

The study therefore concluded that through participatory methods the following information was generated:

1. Rice and maize were identified to be major staple foods and cash crops in the area but the potential for rice was higher than any other crop. Rice was more profitable, its consumption was higher than other crops and it was grown by almost all households surveyed.

2. Rice farming has been identified as a major economic actively in the area and more active participation of women than men were also noted suggesting that woman's involvement and utilization of their indigenous knowledge and understanding their preferences for rice varieties may increase adoption of new varieties.

3 The study also found that although the majority of farmers in the area involved themselves largely in rice cultivation, there was the fact that income generated through off-farm involvement eased the liquidity constraints for farm operations and soil conservation investments or purchase of fertility enhancing inputs.

4. Soil degradation through increased salt affected soils and drought were identified as the major factors responsible for irrigated rice yield decline in both villages. The awareness on existence of salt affected soils problem in farmers' fields was high, and the majority of farmers perceived SASs as a major problem that needed serious attention as it caused dramatic yield losses. The majority of farmers claimed that the problem was increasing and there was no strong mitigation efforts advocated to remedy the problem.

5. Major varieties grown included: 1R 56, IR 54 (in Mkomazi) and IR 64, TXD 306 (SARO 5) (in Mombo) . These varieties are high yielding but susceptible to salt damage. Salt tolerant varieties are unavailable. Furthermore, the information on the availability and the use of salt tolerant varieties is also unavailable to farmers in these communities. This was also related to the very low use of improved agriculture technologies. Implying that, improving farmers' preferred rice varieties for salt tolerance will provide a great contribution towards increasing rice yields and improve livelihood of the farmers in salt affected soil communities.

6. The study revealed that most preferred traits of rice cultivars were high yield potential, early maturing, aroma, medium plant stature, tolerance to salt and drought. Improvement

of these characters in new varieties for salt tolerance would enhance productivity with likely positive impact on small farmers' food security, incomes and livelihoods.

7. There was no official awareness and capacity building program to promote practices that would alleviate SASs problem. People did some coping strategies as their own choice. Though this is a need-based activity, its sustainability requires awareness and a strong technical involvement to increase the yield.

Therefore, the use of integrated management practice which will involve the use of salt tolerant varieties, improved drainage, use of soil amendment and improved farmer knowledge and information on the SASs problem is highly advocated. In this case, the suitable rice ideotypes should be developed for different environments according to farmers' needs and, this should be complemented by the possible methods to amend the SASs problems from the technical as well as the socio-economic point of view. Furthermore, efforts for prevention of the problems developing in the currently non-salt affected areas in the region and its vicinity are highly recommended.

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Chapter Three

Soil characterisation for salt problems in selected rice irrigation schemes of North Eastern Tanzania, a key aspect towards improvement of salt tolerance in rice

Abstract

Rice (*Oryza sativa* L.) is much more profitable than any other crop in the North-eastern Tanzania. Farmers have complained of increasing salinity and/or sodicity in their rice fields which lessen their yields. Limited information is available regarding these production conditions. Therefore, conventional soil surveys and focus group discussions were used to characterize rice growing irrigation schemes in some parts of Kilimanjaro and Tanga regions. Results showed that there were 27 rice irrigation schemes. Tanga had relatively higher irrigated rice production opportunity than Kilimanjaro. Soil analysis revealed that 7 out of 9 surveyed schemes were affected by salts. Soils with EC of up to 10.5 dSm^{-1} and SAR of 72 have been recorded indicating extreme levels of salinity and sodicity, respectively. Saline-sodic soils showed to be the common problem in almost all affected schemes in the area. Results from water samples collected from main canals serving surveyed schemes also indicated the presence of slight to moderate sodicity (Ec_w of 0.08 - 0.47 dSm^{-1}; pH of 6.9 - 7.8 and SAR of 7.3 to 15.1) characteristics. In-field water samples showed very high salinity and sodicity levels with Ec_w of 1 - 3.16 dSm^{-1}, SAR of 17-20 and pH of 7.2 - 8.2, thus irrigation water was of slightly poor quality. Frrom the results it was therefore concluded that both primary salinisation which occurs naturally where the soil parent material is rich in soluble salts, or in the presence of a shallow saline groundwater table and secondary salinisation which occurs when significant amounts of water are provided by irrigation, with no adequate provision of drainage for the leaching and removal of salts contribute to the problem. Use of salt tolerant cultivars in conjunction with improvement of drainage systems and soil reclamation are highly advocated.

3.0 Introduction

Rice (*Oryza sativa* L.) is much more profitable than any other crop in the North-eastern Tanzania. The crop is produced mainly under rain-fed lowland and irrigation schemes. Participatory rural appraisal (PRA) conducted in Mombo and Mkomazi rice irrigation schemes in 2008 and reported in chapter 2 of this thesis indicated that, salt affected soils and drought were the major rice production constraints in the area. Farmers have complained of increasing salinity and/or sodicity in their fields and requested that the problem required attention. Severe yield losses were reported in these areas. Figure 1 summarizes information collected from Mombo and Mkomazi village administrative offices indicating yield differences from salt affected and non-affected farmers' fields.

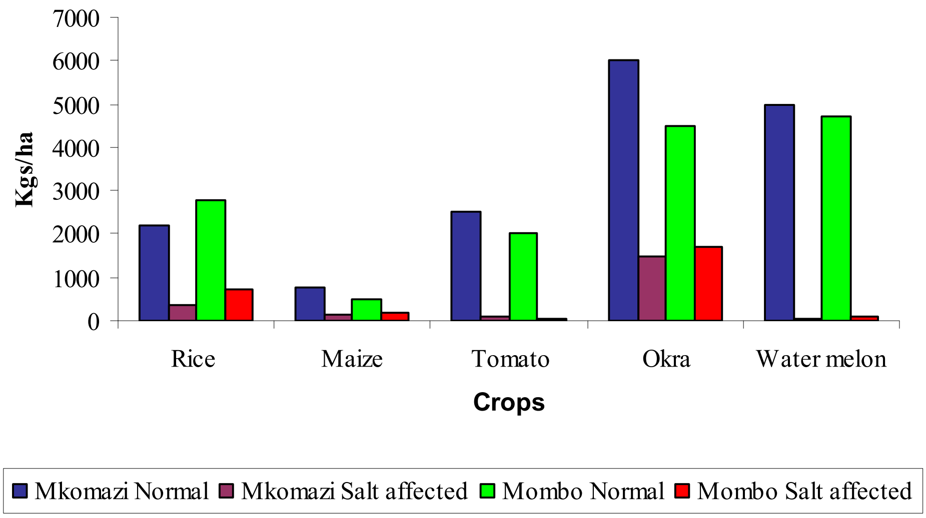

Figure 3.1 Differences in productivity between salt affected and non-salt affected fields for different crops.

Soil is one of the most important natural resources, especially in a country like Tanzania where agriculture is the main source of income and employment for the majority of the population (80% of its more than 36 million people) (Kafiriti 2004; FAO, 2004). Nonetheless, information on Tanzania salt-affected soils in particular, is very scarce and lacks sound verification. Tanzanian soils are suffering from various forms of degradation leading to decreasing productivity. Water and wind erosion are the most severe forms of degradation, but the soils are also physically degraded through compaction and structural breakdown, biologically degraded through removal of organic matter, chemically degraded through continuous removal of nutrients and through development of salt-affected soils particularly in the more arid or semi-arid areas under irrigation (Makoi and Ndakidemi, 2007).

Salt-affected soils (SAS) refer to both saline and sodic soils, which are classified under the major groups of Solonchaks and Solonetz respectively in the FAO-Unesco soil classification system. These classes include: salt-affected soils which contain an excess of water soluble salts (saline soils), excess exchangeable sodium (sodic soils), respectively, or both (saline-sodic soils) (FAO, 2000; Siyal, *et al*., 2002; Waskom *et al.,* 2006). These soils contain appreciable quantities of soluble salts and/or salt-containing compounds in their profile that adversely affect the growth of most crop plants (Chinnusamy *et al*., 2005). Salt-affected soils are common in arid and semi-arid regions of the world where annual precipitation is insufficient to meet potential evapotranspiration (Sahin *et al.,* 2002). The salts may originate mainly from dissolution or weathering of rocks and soil minerals, groundwater (primary cause) or human activities such as use of saline water for irrigation purposes (secondary cause) (Waskom *et al.,* 2006). Salty water from groundwater tables within a few meters of the surface can move upwards by capillary action to the soil surface, where the water evaporates and leaves behind the salts (Alam, 2006; FAO, 2000).

This study was therefore, undertaken in the major irrigated rice production areas of North Eastern Tanzania, to have clear understanding of the bio-physical characteristics of rice growing environments, specifically on the existing type and extent of salt problem in the available rice irrigation schemes. The information is regarded as vital for future management planning and the development of salt tolerant rice genotypes. Selection of research domain was guided by the hypothesis that the area focused has increasing potential for rice production but the opportunity has not been well utilised due to inadequate information on performance as well as production constraints particularly those related to salt development in soils.

The study objectives were therefore to:

1. identifying available rice irrigation schemes and the proportion affected by salt in the North-eastern Tanzania; and
2. determine the extent of the salt problem in both soil and irrigation water in the selected schemes in North-eastern Tanzania.

Research questions addressed in this case included:

(i) how many schemes are available and what are the area under rice production?

(ii) what is the proportion of the area affected by salts in these rice irrigation schemes?

(iii) which type of salt affected soil is common in the area?

(iv) what are the associated visual symptoms indicating the existence of such salt problem

(v) what is the major contributing factor to salt development in these schemes?

3.1 Research Methodology

3.1.1 Description of the study area

North Eastern Tanzania comprises Tanga and Kilimanjaro regions. It borders Kenya in the North, the Indian Ocean in the East, Morogoro and Arusha regions in the West and Coastal region in the South. The low land of North-eastern Tanzania described as a semi arid zone, experiences a weakly bimodal rainfall pattern. The short rainy season starts from November and ends in December, while the long rainy season starts in mid-March and ends in May. Generally, short rains are unreliable and poorly distributed. The mean annual rainfall ranges from 600 to 1200 mm per annum with 60 - 65% of the total rains falling in the months of March through May. January to March is the hottest (30-35^{o}C) and June to August is the coolest months (19-25^{o}C). Relative humidity ranges between 58% (February) to 89% (May). Four districts were involved in the study i.e. Korogwe and Lushoto from Tanga region and Same and Moshi rural from Kilimanjaro region. A list of irrigation schemes were assessed using available reports. Nine irrigation schemes were selected from the list and visited (Figure 3.2). A selection criterion was the potential area currently under rice production.

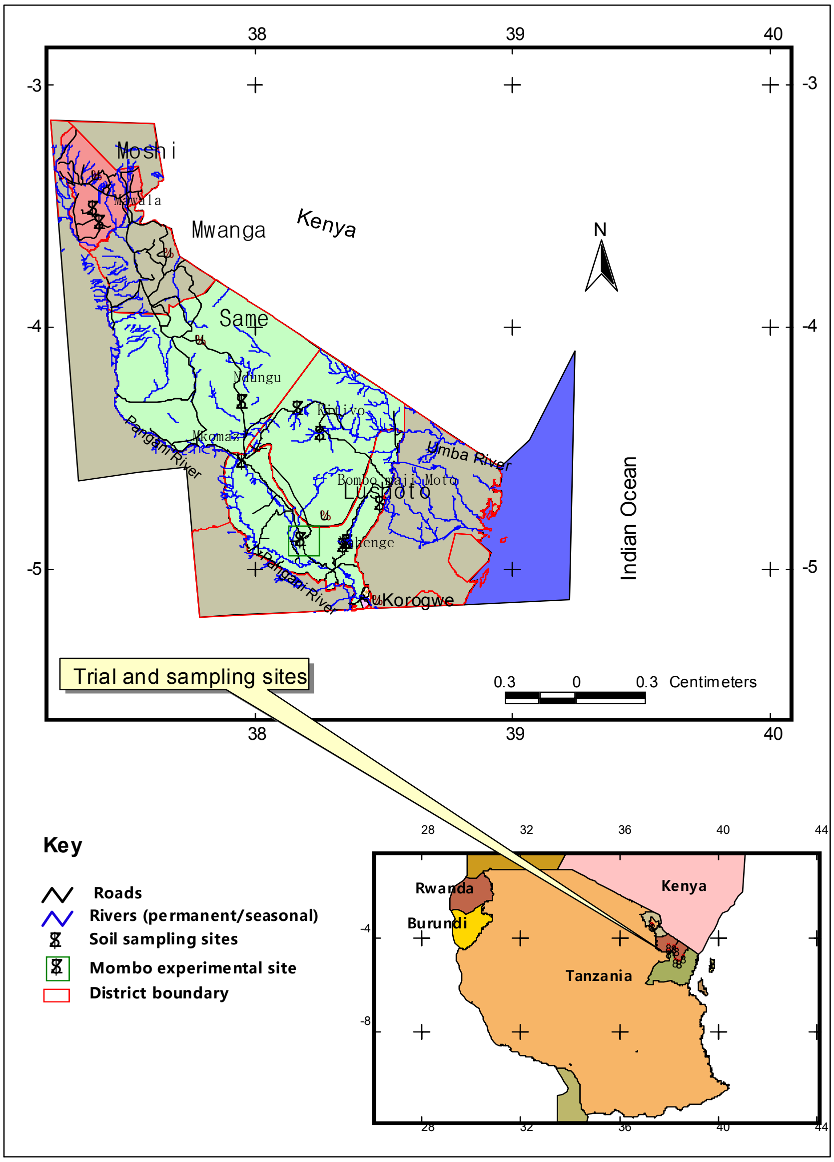

Figure 3.2 Nine rice irrigation schemes in the North Eastern Tanzania.

3.1.2 Data source

Both secondary and primary data were used to get the necessary information. Secondary data were gathered from reports provided by Government services and Non-Governmental Organisations (NGOs). Written documents were supplemented by interviews of key informants such as village and scheme leaders, and extension agents. Data were collected on location, size of irrigation schemes, extent of the salt problem and rice production situation. The information from village leaders, key informants and extension leaders, supplemented by various village reports helped to determine qualitatively the extent of the salt problem in the respective irrigation schemes. Participatory diagnosis (PD) and Observation and Laboratory Soil analysis (ObS) were the main techniques used to generate additional data. Observation involved walks along farmers' fields and direct observations of water distribution system, soil condition and rice plants. Parallel to this soil and water samples and pictures showing background of the situation were collected for analysis. The extremely affected fields were marked using Geographical Positioning System (GPS).

3.1.3 Soil and water sampling

From the list of irrigation scheme, soil sampling was done in nine selected schemes and water samples were taken from seven out of the nine selected schemes. Three fields in from each irrigation scheme covering the different setting with and without SASs indicators where rice is grown were identified and sampled. Presence (or absence) of vegetative cover and/or deterioration of vegetation as well as farmers' experience on rice performance were criteria used to define targeted salt affected areas. Soils were sampled with a soil auger to a depth of 100 cm. Composite samples were taken from two depths, the upper (0-20cm) and sub soil (30-50cm). Each composite sample was compounded from five sub-samples collected within an area of about 25m radius of the observation point, well packed, and labelled for laboratory analysis. In order to ascertain the possible causes of salt problems in the fields from irrigation water, water samples were collected in 500 mls bottle capacity (in three replication) from the main scheme water intake canals and from irrigation canals within farmers field.

3.1.4 Soil and water samples analysis

Both soil and water samples were taken for analysis at The National Soil Service laboratory, ARI-Mlingano. Table 1 summarises parameters that were analysed and method of analysis used. The analysis made for water samples focused on the amount of major cations and anions dissolved in the water (Mg^{+2}, Ca^{+2}, Na^{+} and K^{+}), pH (KCl and H_2O) as well as electrical conductivity (ECw).

Table 3.1 Soil chemical analysis and methods used in the study*

Soil property	*Method of analysis*
Soil reaction, pH (H2O)	pH meter, soil: water (1:2.5)
Electrical conductivity (d S m-1)	EC meter, soil: water (1:2.5)
Organic carbon (%)	Walkey-Black method
Total Nitrogen (%)	Macro Kjeldhal digestion
Available P (mg kg-1)	Olsen's method
Exchangeable Bases (meq 100g-1)	EDTA Titration of 1M ammonium
Cation exchange capacity (meq 100g-1)	1M ammonium acetate extract
Exchangeable sodium percentage (ESP)	By calculation
Sodium adsorption ratio (SAR).	By calculation

(*Klute, 1986).

3.1.5 Data analysis

Soil samples were analysed using standard chemical analysis (Table 3.1) in the laboratory (Klute, 1986). Data were analyzed using GENSTAT release 11 (Payne *et al.,* 2008) computer package. The parameters were compared using the Bonferroni test (Miller, 1981).

3.2 Results and discussion

3.2.1 Rice irrigation schemes of North Eastern Tanzania

Results showed a high potential for irrigated rice production in the study area. Tanga region has relatively higher irrigated rice production potential by having a number of irrigation schemes and water sources than Kilimanjaro region. More than 21 out of 27 irrigation schemes are located in Tanga region and 17 out of the 21 schemes are located only in Korogwe district (Table 3.2). The region has 39,777 ha suitable for irrigated rice production, however only 11,944 ha (which is 29%) is currently under production. It is estimated that only 25% of rice production in the region comes from these areas. In this case a potential still exists for increasing irrigated rice production in Tanga region.

Table 3.2 Rice irrigation schemes available in Tanga and Kilimanjaro Regions

Schemes	Area (ha)
Tanga: Korogwe	
Mombo	220
Chekelei	177
Mazinde	120
Manga/Bwiko	>150
Mkomazi	>1000
Bombo Makorokoro	>80
Mombo Kidundai	70
Manga/Goha,	90
Mtindiro	30
Mkumbara	30
Kwemazandu	100
Mahenge	90
Magoma	100
Makorora	50
Kwamgumi	80
Kerenge/Kibaoni	60
Kiloza	70
Tanga: Lushoto	
Kwemkazu	100
Kivingo/Chaula/ Antakae	60
Mng'aro/Kitivo/magereza/Longuza	>800
Kwemdimu/ Bendera	30
Kilimanjaro: Same	
Kihurio	>300
Ndungu	>680
Kilimanjaro: Same	
Kileo	>500
Lower moshi	1104
Mawala	>400

Source: Regional Commissioners Office (1993)
Regional Development report (1992)

3.2.2 Selected irrigation schemes and major land characteristics

The surveyed area covered nine selected irrigation schemes, their sites and coordinates were indicated in Figure 3.2 and Table 3.3, respectively. These irrigation schemes combine those with improved irrigation infrastructures (Chekereni, Kitivo, Mombo and Ndungu) and those with un-improved - local infrastructures (Mawala, Mkomazi, Bombo makorokoro, Kwemkazu and Mahenge). Rice growing areas in these irrigation schemes is dominated by wide river flood plains. The soils in the valley bottoms are flooded during the rainy season, whereas the soils on adjacent dry lands are aerobic and erosion prone.

River flood plains are characterized by a wide, flat plain of alluvium bordering streams and rivers that flood it periodically. Well - developed floodplains extend for tens of meters to tens of kilometres on either side of rivers.

Table 3.3 Location and proportion of salt affected soils in selected rice irrigation schemes of North-eastern Tanzania

Location/Districts	Scheme name	Coordinates	Elevation (m a.s.l)
Korogwe: Tanga	1. Mombo	04^o 39.095'S 038^o 41.250'E	400.18
	2. Mahenge	04^o 24.669'S 038^o 26.250'E	326.14
	3. Bombo Majimoto	04^o 24.669'S 038^o 22.250'E	392.89
	4. Mkomazi	04^o 39. 241'S 038^o 04. 164'E	452.32
Lushoto: Tanga	5. Kitivo	04^o 22. 783'S 038^o 04. 958'E	407.21
	6. Kwemkazu	04^o 24.669'S 038^o 19.250'E	499.57
Same: Kilimanjaro	7. Ndungu	04^o 22. 783'S 038^o 04. 958'E	497.74
Moshi rural: Kilimanjaro	8. Chekereni	03^o 27. 989'S 037^o 24. 380'E	723.90
	9. Mawala	03^o 31. 039'S 037^o 26.059'E	712.93

The surveyed areas covered irrigated and non-irrigated sites within the farm. The irrigated sites were planted with rice. The non-irrigated sites could be divided into two: land that was cultivated during the rainy season and land that was currently uncultivated due to its salt problem. The non-irrigated areas were being used as grazing or fallow land at the time of sampling. There were some bare patches without grass where a dark brown crust was seen on the surface of the soil. Mkomazi and Mawala areas had more of bare land patches than other schemes and water still remained on the surface in these bare areas, it had not drained nor infiltrated into the soil. The soils in these areas also showed poor workability and were difficult to dig.

Characteristics of soil degradation due to salinisation and sodification processes were observed mostly by professional visual examination and farmers' explanation using local indicators of salt soil degradation. These indicators included patchy growth (Figure 3.3a), seedling wilt after transplanting, seedling leaf senescence, and salty spots on dry surface as indication of salinity (*Chumvi)* (Figure 3.3b). Other characteristics include too blackish soil due to disintegration of organic matter, slippery and soapy feeling when wet, poor structure and extremely hard to till when dry and tasting of bi-carbonate (*Magadi*) as an indication of sodicity (Figure 3.3c and d).

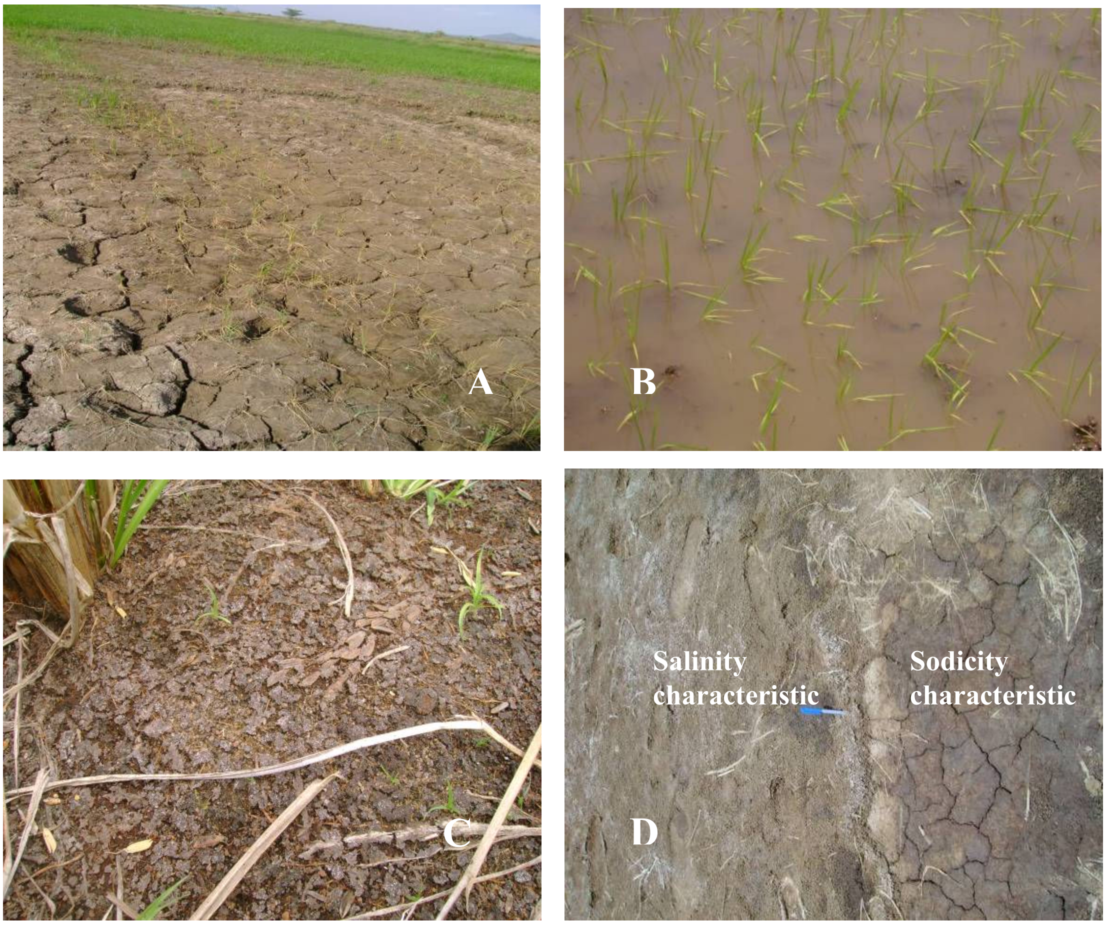

Figure 3.3 Different Salt affected soils rice fields in the North-eastern Tanzania:
A) Severely salt affected and abandoned field at Mkomazi irrigation scheme – Korogwe, Tanga. B) Seedling affected by salt at Mawala irrigation scheme – Moshi rural, Kilimanjaro C) Abandoned salt affected rice field at Kitivo irrigation scheme – Lushoto, Tanga. D) Saline and sodic characteristics in the same field as described by farmers at Mkomazi irrigation scheme – Korogwe, Tanga

These local indicators and their technical equivalents refer to problem soils and a wider sense of nutrients supply is indicated in Table 3.4. These characteristics were observed at varying degrees in 7 out of 9 surveyed irrigation schemes indicating different levels of SASs. Similar characteristics for identification of SASs have been mentioned by earlier studies (Siyal *et al*., 2002; Waskom *et al.,* 2006).

Table 3.4 Most important local indicators of salt affected according to the assessments in visited schemes at Korogwe, Lushoto, Same and Moshi rural districts

Local indication	**Technical indication**
Salty soil	
- Black colours	- High pH
- Compacted soils	- Physical, chemical and biological limitation
- Stunted growth	- Low biological activity
- Presence of bracken ferns and some specific plants	- Presence of major dissolvable ions,
	- Hard pans and salt on the soil surface
- Salt visible on surfaces	- Shallow soils
Good soil	
- Mixed succulent vigor growth of vegetations	- Adequate supply of growth factors
- Black light soil	- Large supply of plant nutrients
- Less cracks during dry season	- High water holding capacity (WHC)
- Good crop performance	- High infiltration rate and WHC
- Abundance of various small animals	- High biological activity, high organic matter content - and neutral pH.

3.2.3 Status of salt affected soils in the irrigation schemes of the North-eastern Tanzania

The results showed that the salt affected areas in all visited schemes ranged between 10 and 35% of cultivable land with an average of 15% (Table 3.5). Mkomazi scheme showed to have more of affected areas than other irrigation schemes. Soil analysis results revealed that all measured chemical properties varied significantly ($p<0.001$) with depth within the same field and between the surveyed irrigation schemes. The soil contents of the root zone varied with depth (form 0-20cm to 30-50cm), the contents were lower in upper layer and higher in the lower layers, indicating the lower layers were more salty and had higher pH levels than the top soil (Table 3.6). This could be due to the reason that plant extracting water but leaving salts behind in a greatly reduced volume of soil: water, and each subsequent irrigation pushes (leaches) the salts deeper into the root zone depth where they continue to evaporate. Ayers and Westcot (1985) reported that soil salt concentration increases with depth and it varies from approximately that of the irrigation water near the soil surface to many times that of the applied water at the bottom of the rooting depth.

Table 3.5 Characteristics of surveyed rice irrigation schemes, in the North-eastern Tanzania

Location/ Districts	Schemes surveyed	Land forms	Area (ha)	Soil texture	Crops grown	Soil related Production constraints	% area affected by salts
Korogwe: Tanga	1. Mombo	Foot slope of East Usambara Mts	220	sandy loam to sand clay subsoil	Paddy	Poor fertility in some part sodic and saline	15
	2. Mahenge	Valley bottom	80	sandy loam to sand clay subsoil	Paddy, banana	Poor fertility in some part sodic and saline	10
	3. Bombo maji Moto	Narrow valley bottom	> 90	Clay_loam	Paddy, maize, cocoyams	Poor fertility in some part salty	15
	4. Mkomazi	Foot slope river depression	>1000	Topsoil sandy clay loam, and subsoil sandy clay	Paddy, maize	strong sodicity and saline, poor fertility	35
Lushoto: Tanga	5. Kitivo	Foot slope plain West Usambara Mts	>800	Clay_loam	Paddy, maize, beans, cassava	strong sodicity and saline, poor fertility	15
	6. Kwemkwazu	Foot slope plain	>100	Sandy clay loam to clay	Paddy, maize, beans, cassava	strong sodicity and saline, poor fertility	10
Same: Kilimanjaro	7. Ndungu	Foot slope of Pare Mts	> 680	Clay_loam topsoil to clay subsoil	Paddy	saline-sodic, poor fertility	15
Moshi rural: Kilimanjaro	8. Chekereni	Foot slope of Mts Kilimanjaro	> 700	Sandy clay	Paddy, banana, maize	Poor soil fertility	-
	9. Mawala	Foot slope of Mts Kilimanjaro	> 500	clay loam	Paddy, maize, and banana	Poor fertility in some areas strongly sodic	15

Table 3.6 Chemical properties of soils in rice irrigation schemes of North-eastern Tanzania

Site	Depth (cm)	pH (H20)	EC1	Ca^2	Mg^2	Na^2	SAR	Soil characterization
Bombo	0-20	5.9a	0.7ab	3.2a	2.4b	1.4a	8.7b	Normal
Makorokoro	30-50	7.3b	1.3b	20.7d	14.7d	4.4a	10.1ab	Normal
Chekereni	0-20	6.1b	0.3a	10.2.c	3.6c	0.6a	1.6a	Normal
	30-50	7.2ab	1.9a	12.7b	3.8b	0.8a	2.1a	Normal
Mahenge	0-20	6.4b	0.7ab	3.3a	3.5c	1.3a	9.2b	Slightly Sodic
	30-50	8.0abc	2.3c	15.7c	13.8d	6.2a	16.9bc	Slightly Saline-Sodic
Ndungu	0-20	8.1c	6.6d	39.0f	22.0f	14.5c	21.7d	Strongly Saline-Sodic
	30-50	8.2abc	9.1e	47.6f	24.0e	21.1bc	24.8cd	Strongly saline-sodic
Kwemkwazu	0-20	8.1c	8.0e	35.3ef	14.4e	14.3c	22.7d	Strongly saline-sodic
	30-50	8.4abc	10.1f	40.7e	11.7d	14.4b	23.9cd	Extremely saline-sodic
Kitivo	0-20	8.4c	11.7f	32.7e	14.4e	14.5c	27.8e	Extremely saline-sodic
	30-50	8.5bc	9.2e	15.2d	14.7d	14.9b	31.9d	Extremely saline-sodic
Mombo	0-20	8.3c	4.0c	15.2b	4.5d	6.8b	16.2c	Slightly saline- sodic
	30-50	8.6c	4.2d	14.6cd	4.7b	6.8a	17.2bc	Strongly Saline-Sodic
Mawala	0-20	9.7d	2.0b	12.5ab	2.3b	21.7d	57.2f	Extremely Sodic
	30-50	10.3d	3.5d	14.8b	1.9a	23.5c	75.2	Extremely Sodic
Mkomazi	0-20	10.1d	6.9de	7.4b	0.7a	33.5e	62.3f	Extremely saline- sodic
	30-50	10.3d	6.6de	20.5d	1.4a	50.5d	82.4e	Extremely saline- sodic
F Pr	*0-20*	***	***	***	***	***	***	
SED		*0.2*	*0.08*	*0.1*	*0.04*	*0.2*	*0.6*	
LSD0.05		*0.49*	*0.18*	*0.21*	*0.09*	*0.42*	*1.2*	
F Pr	*30-50*	***	***	***	***	***	***	
SED		*0.3*	*0.5*	*0.2*	*0.31*	*1.8*	*3.4*	
LSD0.05		*0.7*	*0.1*	*0.35*	*0.66*	*3.8*	*7.2*	

1mmho/cm= mS/cm=dS/m
2Cmol/ (+) kg soil = meq/L × equivalent weight (mg/meq)
SAR = Na/ (((Ca+Mg)/2)1/2)
Ece Standards: 0-4=Non-saline; 5-8=slightly saline; 9-15=moderately saline; > 15=strongly saline
ESP Standards: 0-5=Non-sodic; 6-10=slightly sodic; 11-15=moderately sodic; 16-25=strongly sodic; 26-35=Very strongly sodic; >35 extremely sodic.
Within a column, means followed by same letter(s) are not significant different at P < 0.001, according to Bonferroni test

3.2.3.1 Soil pH

Analysis of individual chemical properties from composite soil samples shows significant (P<0.001) soil pH variability between the surveyed schemes (Table 3.6). Soil pH indicates whether the soil is acidic, neutral or alkaline. Plants and soil microorganisms show a marked response to soil reaction since it has a major influence on the soil chemical environment and on the availability of essential nutrients. A normal pH for soil or water ranges from 6.0 to 8.0, a pH beyond this range can cause nutritional and growth problems for most of crops (Ayers and Westcot, 1985). When pH becomes too acidic or too alkaline a range of problems occur, including deficiencies in the availability of various nutrients and direct toxicity.

The study result identified soil pH ranges of a range from 4.9 - slightly acidic (in Bombo majimoto) to 10.1 - very strong alkaline (in Mkomazi) (Table 3.6), with an average of 8.2 indicating slightly alkaline. Maas (1990) commented that high pH values above 8.5 are often caused by high bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) concentrations. Soils of arid and semi-arid regions are commonly alkaline due to an accumulation of carbonates in the soil (Acquaah, 2007). Maas (1990) added further that high carbonates causes calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant cation in solution. This is well evidenced by low calcium and magnesium level and extreme levels of sodium in Mawala and Mkomazi schemes where the soil pH was as high as 10. In sodium-rich clays, HCO_3 react with water to form hydroxyl (OH-) ions that cause high pH (FAO, 1988; Brady 1990).

3.2.3.2 Soil Salinity

Salinity refers to the total concentration of all salts in the soil. The salts are usually chlorides, sulphates, carbonates and bicarbonates of calcium, magnesium, sodium and potassium. High concentrations of soluble salts are detrimental to plant growth particularly because water availability is reduced, as well as due to direct toxicity from some ions such as sodium and chloride, and ionic imbalances created in the plants (Tollenaar, 2002). Salinity is a common problem in arid and semi-arid areas, particularly where irrigation with water containing dissolved salts is practiced, due to the fact that as water evaporates from the soil surface the salts remain in the soil and accumulates over time (FAO, 2004). Salts dissociate into positive and negative ions in solution and therefore have the ability to conduct an electric current.

Salinity is therefore measured as electrical conductivity of a saturated soil extract or paste (ECe), where the soil: water ratio is 1:2 (in this case a ratio of 1:2.5 was used). A soil is classified as saline if it has an ECe value of 4.0 or more dS m^{-1}, although some plants, particularly for example fruit and vegetable crops, are sensitive to lower salinity levels down to 2.0 d Sm^{-1} (Chinnusamy *et al.,* 2005). Significant variation of soil EC at 25^oC ($P<0.001$) was observed between schemes (Table 3.6). The irrigated soils of the North Eastern Tanzania showed EC values ranging from 0.3 dS m^{-1} (Chekereni scheme) to 11.7

dS m^{-1} (Kitivo scheme). These ranges showed very low to extremely high salinity levels indicating that the soils had a significant input of salts from either their parent materials or from the water used for irrigation, and that the crops were likely to be affected.

According to the classification of crop tolerance to salt affected soils, the rice crop is within the sensitive division from 0 to 8dS/m (Mass, 1986). Chinnusamy et al. (2005) reported further that a threshold salinity level for rice is 3.0 dS m^{-1}. According to FAO (2005), if the EC (e) is less than 4, the yield loss will be less than 10%; if the EC (e) is more than 6, the yield loss will be 20 – 50% and when the EC (e) is more than 10, then yield loss will be more than 50%. This indicates that, potential high yield losses occur in Ndungu, (6.6 dSm^{-1}), Kwemkwazu (8 dSm^{-1}), Mkomazi (6.9dS m^{-1}) and Kitivo (11.7 dSm^{-1}) irrigation schemes (Table 3.6).

3.2.3.3 Soil alkalinity and sodicity

Soils containing sodium salts have particular problems since high levels of sodium ions (Na^{+}) cause clays to disperse, which breaks down the soil structure, decreases porosity and lowers the permeability of the soil to water and air. According to ILACO (1989) medium soil nutrient requirement to expected 80-100% crop yield without the use of fertilizers are 0.3-0.6 for K^{+}, 1.5-3.0 for Mg^{2+}, 5-10 for Ca^{2+} and 0.3-0.7 for Na^{+}.

Exchangeable sodium in a soil is also reported as the Sodium Adsorption Ration (SAR). This is a unit-less ratio of the amount of cationic (positive) charge contributed to a soil by sodium to that contributed by calcium plus magnesium. A desirable value for SAR is below 13. Above 13, exchangeable sodium can cause soil structure deterioration and water infiltration problems (Cardon and Mortvedt, 1994). If the SAR is more than 13 and it is also associated with high pH (of 8.5 or more) then the soils are classified as **sodic.**
The irrigated soils in North Eastern Tanzania have an average SAR range between 1.6 (Chekereni) indicating there is no sodicity problem to 62.5 (Mawala) indicating high sodicity problems. All the tested sites except Bombo makorokoro and Chekereni had SAR > 13 indicating the existence of sodicity problems in both top and sub soils. Extremely high levels of Na and low level of Mg and Ca caused by high SAR were

observed in Mkomazi and Mawala indicating high levels of sodium which was also associated with high alkalinity (Table 3.6).

Results also identified that saline-sodic followed by sodic soils are major SAS problem in the North eastern part of Tanzania. The results therefore, are in line with farmers' results reported in chapter two of this thesis that salt affected soils are the major rice production constraints in the area. This has been confirmed by analysis of composite soil samples collected from seven irrigation schemes i.e. Ndungu, Mahenge, Kwemkwazu, Mombo, Kitivo, Mawala and Mkomazi (Table 3.6). Studies by Wickama *et al*. (2006) and Makoi and Ndakidemi (2007) reported a similar finding in Kileo irrigation scheme and some lowland areas of Northern Tanzania used for rain-fed and irrigated maize production.

3.2.4 Water quality and irrigation infrastructure

A significant difference in water quality characteristics was observed between irrigation schemes. Differences were observed in samples collected from both water source and within farmers' fields (Table 3.7 and 3.8). The results therefore indicated that water samples collected in all six irrigation schemes had high SAR indicating sodicity characteristics. Analysis of water samples collected from water sources showed moderate to slightly sodic characteristics which indicated slightly poor irrigation water (Table 3.7), whereas, water samples collected from ground water within farmers' fields indicated strongly sodic and saline-sodic characteristics (Table 3.8).

These characteristics of water samples show the probability that the salt problem is caused by both irrigation water and natural weathering of parent materials within farmers' fields. According to Ayers and Westcot (1985) water is safe for supplementary irrigation if the electrical conductivity (EC_w) is less than or equal to 1.0 dSm^{-1} and the sodium adsorption ratio (SAR) is less than or equal to 5. If EC_w is greater than or equal to 2.0 dSm^{-1} and/or SAR is greater than or equal to 10, the water is unsuitable for irrigation. Saline-sodic irrigation water with EC_w between 1.0 to 2.0 dSm^{-1} and SAR of 5 to 10 may negatively affect the structural stability of the soil. Irrigation water with SAR value below 6 is preferable; when the value exceeds 9 soil structure can deteriorate, resulting in slower water infiltration and reduced soil aeration (Buckland, 2002). The study further recommended that soil structural stability should be determined annually if these waters are used for irrigation.

Table 3.7 Chemical analysis of water samples collected from irrigation schemes water sources in the North-eastern Tanzania

Samples site	Ec_w (dS/m)	pH (1:2.5)	SAR	Quality classification
Kitivo	0.24ab	6.9a	11.6ab	Moderately sodic
Mawala	0.34ab	7.8b	9.17a	Slightly sodic
Bombo Mkorokoro	0.47b	7.7b	14.60b	Moderately sodic
Mkomazi	0.44b	7.8b	15.13b	Moderately sodic
Ndungu	0.08a	7.3ab	7.30a	Slightly sodic
Kwemkwazu	0.13a	6.9a	9.40a	Slightly sodic
Fpr	***	***	*	
SED	0.07	0.05	2.2	
LSD $^{0.05}$	0.16	0.11	4.9	

*** =Highly significant at $P < 0.001$, ns = non - significant
Within a column, means followed by same letter(s) are not significant different at $P < 0.001$ according to Bonferroni test
$SAR = Na/ (((Ca+Mg)/2)^{1/2})$
If $EC_w = \leq 1.0$ dS/m and SAR = ≤ 5 means safe water for supplemental irrigation. If $EC_w = \geq 2.0$ dS/m and SAR = ≥ 10, the water is saline - sodic and unsuitable for irrigation. Saline-sodic irrigation water with EC of 1.0 - 2.0 dS/m and SAR of 5 - 10 may cause salt build up and hence negatively affect the structure of soil. (Ayers and Westcot, 1985)
[1]mS/cm=dS/m = mmho/cm

Table 3.8 Chemical analyses of ground water samples collected within farmers fields in the North - eastern Tanzania

Samples site	ECw	pH (1:2.5)	SAR	Quality classification
Kitivo	0.27a	7.2b	18.53a	Moderately sodic
Mawala	0.35ab	8.1c	37.30d	Strongly sodic
Bombo Mkorokoro	1.01b	7.2b	25.33c	Strongly sodic
Mkomazi	2.11c	8.0c	36.13d	Strongly saline-sodic
Ndungu	2.3cd	7.7bc	11.10b	Moderately Saline sodic
Kwemkwazu	2.6d	6.2a	27.42c	Strongly saline - sodic
Mkomazi wind Mill	2.8de	8.2c	46.77e	Extremely saline sodic
Fpr	***	***	***	
SED	0.21	0.06	0.64	
LSD $^{0.05}$	0.5	0.14	1.4	

*** =Highly significant at $P < 0.001$, ns = non - significant
Within a column, means followed by same letter(s) are not significant different at $P < 0.001$ according to Bonferroni test
$SAR = Na/ (((Ca+Mg)/2)^{1/2})$
If $EC_w = \leq 1.0$ dS/m and SAR = ≤ 5 means safe water for supplemental irrigation. If $EC_w = \geq 2.0$ dS/m and SAR = ≥ 10, the water is saline - sodic and unsuitable for irrigation. Saline-sodic irrigation water with EC of 1.0 - 2.0 dS/m and SAR of 5 - 10 may cause salt build up and hence negatively affect the structure of soil. (Ayers and Westcot, 1985)
[1]mS/cm=dS/m = mmho/cm

The result showed the probability that, water draining from mountains carried soluble salts with higher levels of sodium in particular, which contribute into sodicity of the water. Brady (1990) reported that the presence of excess salts on the soil surface and in the root zone characterizes all salt affected soils. The main source of all salts in the soil is the primary minerals in the exposed layer of the earth's crust. During the process of chemical weathering which involves hydrolysis, hydration, solution, oxidation, carbonation and other processes, the salt constituents are gradually released and made soluble (Tesfai *et al.,* 2002). Brady (1990) added further that the released salts are transported away from their source of origin through surface or groundwater streams. Salts in the groundwater stream are gradually concentrated as the water with dissolved salts moves from the more humid to the less humid and relatively arid areas (Abro *et al.,* 1998).

According to Ayers and Westcot (1985), salt are added to the soil with each irrigation, crops remove much of the applied water from the soil to meet its evapotranspiration (ET) demand but leaves most of the salts behind to concentrate in the shrinking volume of soil-water. These salts will reduce crop yield if they accumulate in the rooting depth to damaging concentrations (Buckland, 2002). A portion of the added salt must be leached from the root zone before the concentrations affect crop yield (FAO, 2004). Leaching is done by having sufficient water and proper irrigation canal for elimination of leached water from the fields (Siyal *et al* 2002). In this case, the available poor management of irrigation water, poor irrigation canals and skills for water management in most of the local irrigation schemes worsens the situation.

Results show further that irrigation schemes with poor irrigation canals accompanied by inadequate drainage such as Mkomazi, and Mawala have had relatively higher salts hazards compared to irrigation schemes with improved drainage systems (Mombo and Chekereni) (Table 3.7 and 3.8). Poor drainage systems have been identified as source of the factors contributing to the accumulation of salts in the surveyed irrigation schemes in the north eastern Tanzania and elsewhere (Tesfai *et al*., 2002; Buckland, 2002), and probably the potential severity of the problem is expected in the long run if corrective measures are not been considered. Buckland (2002) reported complete failure of some irrigation projects that used saline-sodic and sodic waters, (for example, the Verdigris Reservoir and the Etzicom Coulee-Crow Indian Lake projects in Alberta, and the Cadillac Reservoir-Boule Creek projects in Saskatchewan). These projects have failed due to the adverse impacts of the water on soil structure and crop productivity.

Ayers and Westcot (1985) reported that water with high SAR causes calcium to precipitate and decreases exchangeable calcium, and this can lead to sodicity soil conditions. Sodicity enhances the degradation of tilth of a surface soil; this was clearly shown in sodic and saline – sodic soils collected from Mkomazi and Mombo irrigation schemes respectively (Figure 3.4a&b). The sodic soil from Mkomazi tended to be very black and hard when dry, but became sticky and plastic when wet. According to Mnkeni (1996) sodic soils tend to be dark brown or black due to surface coating of dispersed organic matter.

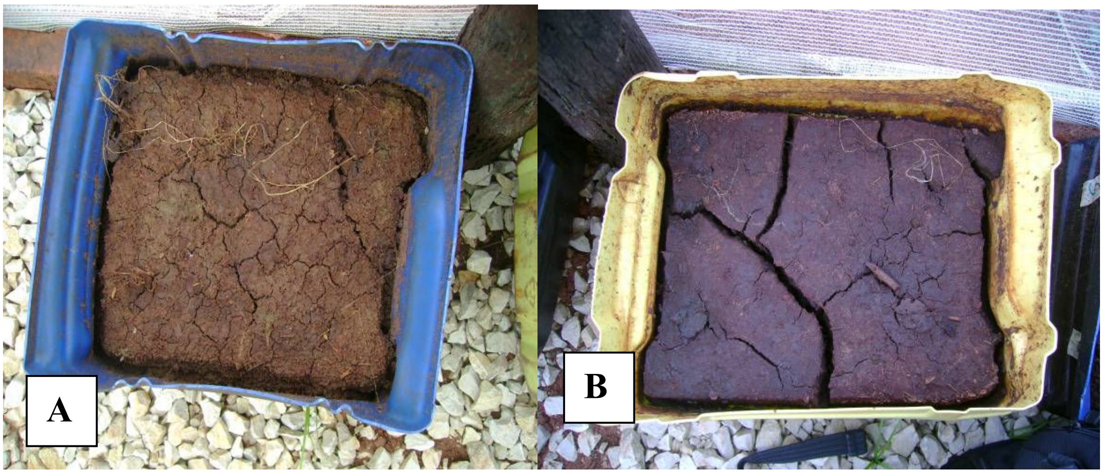

Figure 3.4 Showing (A) Saline-sodic and (B) Sodic affected soils
A= Saline-sodic soil = (ECe = 6.7dSm^{-1}, SAR = 17, pH = 8.0) collected from Mombo irrigation scheme and
B=Sodic affected soils = (ECe = 2.7 dSm^{-1}, SAR = 29, pH = 10.0) collected from Mkomazi irrigation schemes

3.3 Conclusion

The results from the diagnostic survey that are presented above lead to the following conclusions:

1. There is enormous potential for increased rice production in the study area; however salt affected soils in all three classes (sodic, saline and saline-sodic) are the major rice production constraints in the area.
2. The causes of sodicity problems in these irrigation schemes are from both the irrigation water source and from weathering of the parent rock in the field.

3. Seven out of nine studied irrigation schemes were salt affected. This indicates the magnitude of the problem and point toward the importance of developing salt tolerant varieties for the salt prone areas.
4. Poor irrigation canals, poor management of irrigation water were the driving factors that contributed to salt accumulation hence soil degradation, therefore causing declined productivity in the area.
5. The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. In this case the saline-sodic is common in irrigation water in majority of schemes of North eastern Tanzania which also has a significant contribution to increasing saline-sodic soils in most of surveyed irrigation schemes in the area.

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Chapter 4

Comparative performance of some rice genotypes and evaluation of traits associated with stress tolerance under saline and saline-sodic conditions

Abstract

Rice genotypes including local farmer preferred cultivars were tested against saline and saline-sodic salt stresses to evaluate their performance and develop selection criteria for salt tolerance. Two experiments were conducted under controlled environments to evaluate the tolerance of 10 and 11 rice genotypes under saline and saline-sodic stresses, respectively. A hydroponics mass screening technique was used to test the 10 genotypes in NaCl- saline treated and non-treated solutions. Significant variation between genotype and significant interactions between genotype and salt treatment ($P<0.001$) was observed for all characters. Saline stress reduced plant growth of all tested genotypes. Plant vigour and shoot K^+ concentration were relatively more affected than other traits. On the basis of less than 50% reduction in different growth variables, Pokkali displayed significantly superior performance followed by IR67076-2B-21-2 and IR 56 whereas Nerica1 showed the poorest performance. Tolerant rice genotypes were successful in maintaining low Na^+ and high K^+ uptake and low Na^+/K^+ ratio. Further, the 11 genotypes were assessed in 5kg pots containing saline-sodic soil and non-treated soil. Results under saline-sodic conditions indicated that growth was arrested in almost all genotypes. Highly significant differences ($P< 0.001$) among genotypes and their interactions with salt treatments were observed for all characters measured. Plant height and spikelet fertility were relatively more affected, however the magnitude of reduction varied between cultivars. Considering all plant parameters measured, genotype CSR 27 followed by Nerica 2 and IR 56 had relatively less than 50% reduction in variables measured therefore rated relatively tolerant while Kisegese and IR 64 performed more poorly than others. The study therefore established that, all the local farmer preferred cultivars except IR 56 performed poorly under both salt stress environments. High seedling vigour, less leaf injury, less Na^+ and high K^+ accumulation in leaves, low Na^+/K^+ ratio of ion uptake, high spikelet fertility, increased grains per panicle and 1000-grain weight should be considered as desired characteristics while screening the lines for salt tolerance under saline and saline - sodic conditions.

4.0 Introduction

Salinization and sodification of the soils is increasing especially in arid and semi arid regions of the world with negative impact on adequate production of cereals such as rice. FAO and UNESCO reported that nearly 50% of the irrigated lands in arid and semi-arid regions of the world have some degree of soil salinization problems (FAO, 2003, TWAS, 2006). Preliminary studies done in selected irrigation schemes of North-eastern Tanzania and reported in chapter 2 and 3 of this thesis, indicated that increasing salt affected soils was the major rice production constraint in the majority of irrigated rice schemes in the area. Soil analysis revealed that 7 out of 9 surveyed schemes have been affected by high salt contents and about 15-30% of the scheme areas are severely affected, due to which heavy losses in crop yield were reported.

Tanzania spends a large amount of its foreign exchange in importing rice to fulfill the food demands of its rapidly expanding population. In addition the cultivable land is dwindling due to salt affected soils development among other causes of soil degradation. There are less new lands available especially for irrigated cultivation, the available land which can be used as arable land are of poor quality and cannot provide good economic returns. An important aspect of this is gainful utilization of these salt affected areas (Araki *et al.,* 2001). To achieve optimal food production in these areas, the most appropriate and logical choice is to grow salt tolerant crops/cultivars (Khan and Abdullah, 2003).

Studies have been done in support of the predominance of salt stress tolerance in explaining yield improvement in rice (Singh, 2001; Moradi *et al.,* 2003). It has been reported further that salt tolerance varies considerably with the developmental stages in a number of species including rice (Flowers, 2004). Rice is comparatively tolerant of salt stress during germination, active tillering, and towards maturity and is sensitive during early seedling and reproductive stages, however genetic variation exists between genotypes (Mahmood *et al.,* 2004). Bayuelo-Jimenez *et al.* (2002) found that tolerance at emergence followed by seedling survival and establishment are important in the maintenance of optimal crop stand in the field, and ultimately the economic yield.

Improving a given crop or cultivated species for salt tolerance involve reliable screening procedures to search amongst natural diversity within the species, or closely related and inter - fertile species. However, the quantification of salt tolerance poses difficulties, for example, in the field, first, the salt stress may be experimentally uncontrollable due to climatic effects upon rainfall, temperature and water tables; secondly, field heterogeneity for salt is high (Munns *et al.*, 2002) and thirdly, salt uptake and so sensitivity, is modulated by environmental conditions and may affect each variety differently: any parameter which affects the transpiration rate (such as light intensity, temperature and humidity) can change a plant's susceptibility to salinity therefore genotype x environment interactions are highly expected (Yeo *et al.,* 1990; Yeo and Flowers 1989). For that reason, genotype assessments under controlled conditions are highly advocated. In addition, screening for a trait associated with a specific mechanism is preferable to screening for salt tolerance itself (Chaubey and Senadhira, 1994). A range of screening methods have been reported, including field evaluation method, whereby a barren salt affected land was used (Mishra *et al.,* 2006), laboratory techniques as well as pot and solution culture methods. Laboratory techniques and solution culture methods are common greenhouse techniques for screening genotypes under controlled conditions (Singh and Chatrath, (2001)

Studies on the effect of salt tolerance in plants have indicated that salt damage and consequently adaptation to salt is complex, and no single process can account for the variation in the plant's response to salt stress (Yeo *et al*., 1990). Varietal variation has been observed within small (ten or fewer) samples of genotypes in characteristics that mitigate the consequences of salt uptake (Krishnamuthy *et al.,* 2007). Traits for salt tolerance that have been commonly used to identify tolerant germplasm collections have included seedling vigour, shoot and root length, number of productive tillers, culm strength, rates of Na^+ or Cl^- accumulation in leaves, degree of leaf injury and spikelet sterility (Gregorio *et al.,* 1997; Mahmood *et al.,* 2004; Geetha, *et al.,* 2006; Krishnamuthy *et al.,* 2007). The most successful relate to rates of Na^+ accumulation in leaves. Sodium accumulation in leaves has been shown by various studies to relate to salt tolerance in genotypes of rice (Blaha *et al.*, 2000; Mishra *et al.*, 2001; Mishra *et al.,* 2006; Farshadfar *et al.*, 2007). Furthermore, Mishra *et al.* (2006) found low Na^+/K^+ ratio of ion uptake is positively correlated with a high level of salt tolerance and was taken into consideration as a desired characteristic while screening the lines.

Based on several studies in sodicity and salinity stress over the years, such studies have never been done to evaluate rice materials grown under Sub-Saharan Africa environments including Tanzania. It has been reported that rice varieties vary in their tolerance to type and salt levels. Significant variations in phenology, morphology and physiology across environments have also been observed among genotypes (Munns *et al.,* 2006; Davenport *et al.,* 2005). Therefore, a study was established and used both hydroponic and pot based screening methods under controlled conditions to assess the salt tolerance of some farmers' preferred rice cultivars and evaluate the putative traits in the rice materials that contribute to the performance of a genotype under saline and saline-sodic conditions.

The specific objectives of this experiment were to:

1. determime the performance of rice genotypes commonly gown in irrigation schemes of North-eastern Tanzania under saline and saline-sodic conditions, and
2. determine morphological and physiological traits associated with tolerance to saline and saline-sodic conditions at the vegetative and reproductive stages of plant development.

Under these objectives it was hypothesized that

1. genetic variation does not exists for salt tolerance among local cultivated rice varieties.
2. morphological and physiological traits associate with tolerance to saline and saline-sodic conditions can be detected at the vegetative and reproductive stages of rice development

4.1 Material and methods

4.1.1 Germplasm

The study used 13 rice genotypes comprising Pokalli, IR67076-2B-21-2 (abbreviated as IR67076) , CSR 27, Getu (Tolerant checks), IR 29 (a susceptible check), TXD 306, IR 64, IR 56, Thailand, Kisegese, Gigante (Farmer's preffered cultivated varieties) and Nerica 1 and Nerica 2. These cultivars had not been previously evaluated for tolerance to saline and/or sodic stress under local environments. Table 4.1 shows characteristics of all collections involved in the study.

Table 4.121Characteristics of thirteen genotypes used in the study

Genotype	Source[1]	Tolerance test	Characteristics
Pokkali (IR – 4595-4-1-1-3)	IRRI	Saline & Sodic	- A traditional donor for saline tolerance – developed by pedigree breeding method. Saline tolerant, local pureline, early maturing (Chaubey and Senadhira, 1994).
IR67076-2B-21-2	IRRI	Saline & Sodic	Moderately salt tolerant & aromatic pureline
CSR 27 (CSR 88IR-7)	IRRI	Saline & Sodic	A fine grained high yielding variety developed from Nona Bokra/IR 5657-33-2, tolerant to saline and sodic soil environment, and known to tolerate pH 9.6 – 9.9 and adaptation of ECe(dSm^{-1}) < 10. Released variety (Chaubey and Senadhira, 1994).
TXD 306 (SARO 5)	NRI	Saline & Sodic	Semi-aromatic cultivated variety, resistant to lodging, medium maturing, high growth vigour, good milling and cooking qualities, released in Tanzania,
IR 64	NRI	Saline & Sodic	Preferred cultivar (highly grown in Mombo irrigation schemes), tolerant to P and Zn deficiency, iron and boron toxicity, Early maturing, high yielding. Originate from IRRI
Nerica 1	NRI	Saline & Sodic	- Upland aromatic, early maturing variety, high growth vigour, strong calms tolerant to lodge, blast and insects
Thailand	NRI	Saline & Sodic	- Local preferred cultivar (highly grown in Mkomazi and Mombo) irrigation schemes, high yielding, heavy grain weight, medium maturing.
IR 56	NRI	Saline & Sodic	- Preferred cultivar (highly grown in Mkomazi and Moshi) irrigation schemes. High yielding, medium maturing variety. Originate from IRRI
Gigante	NRI	Saline	- Landrace known to have resistance to rice yellow mottle virus
IR 29	IRRI	Saline	Salt sensitive cultivar used as a susceptible check
Nerica 2 (WAB 450-11-1-P31-1-HB)	IRRI	Sodic	- Pure line developed for irrigated environment, slightly tolerant to drought and salinity
Kisegese	NRI	Sodic	- Highly aromatic local land race
Getu (SCR 3)	IRRI	Sodic	- Tolerate pH of 9.8 –10.4 and ECe(dS/m) 6 – 11 (Chaubey and Senadhira, 1994).

[1](IRRI-International Rice Research Institute, NRI- National Rice Research Institute)

4.1.2 Screening of rice genotypes for salinity tolerance (hydroponics based method).

The salt tolerance of rice genotypes were studied in a green house without much environmental control. The screenhouse had well covered roof, but sides were open having only wire gauze and insect proof net. There was no problem of sunlight. The weather data were monitored at Mlingano weather station located 30m from the greenhouse. Seeds of 10 selected genotypes (Table 4.1) were germinated in sterile mixture of soil, sand and manure at 1:1:1 ratio and seedlings were grown for 14 days. Plastic containers of 40 × 25 × 20 cm were prepared for the screening purpose. A styrofoam sheet was cut to fit the top of each container. Five rows with five holes each were made on each styrofoam sheet and a nylon net was placed at the bottom of each styrofoam sheet to prevent the seedling from falling into the solution as described by Gregorio *et al.* (1997). Each styrofoam sheet was floated in a container filled with 4L of distilled water as indicated in Figure 4.1.

4.1.2.1 Plant growth in nutrient solution

After two weeks, the seedlings (at two to three leaf stages) were uprooted, rinsed with sterilized deionised water to remove the soil and were transferred to the prepared containers. Each container had five rows consisting of five genotypes (one genotype per row), and each hole had three seedlings (Figure 4.1). Control genotypes were grown after every one container for comparison. The seedlings were grown in distilled water for three consecutive days and then distilled water was replaced by a nutrient solution prepared using 1ml/L of working solution (Gregorio *et al.*, 1997).

The working solution was prepared using the following stocks: NH_4NO_3 (91.4 g/L), Na_2HPO_4 (35.6 g/L), $CaCl_2$ (117.4 g/L), $MgSO_4$ (324 g/L) and KSO_4 (70.65mg/L) for macronutrient stocks and a combination of $MnCl_2$ (1.5 g/L), H_3BO_3 (0.934g/L) $ZnSO_4$ (0.035g/L), $FeSO_4$ (7.7g/L), CuSO4 (0.031g/L) $[(NH_4)6Mo_7O_{24}]$ (0.13g/L) and $H_3C_6H_8O_7$ (11.9 g/L) was used to make stock solution for required micronutrients (Gregorio *et al.,* 1997; Yoshida *et al.,* 1976). Seedlings were cultured in the nutrient solution for 10 days prior to salinization to allow proper establishment. The nutrient solution was renewed every 8 days and the pH of 5.0 was maintained daily by adding either NaOH or HCl.

Figure 4.1 Seedlings growth in a styrofoam sheets floated on modified Yoshinda solution (Yoshida *et al.*, 1976)

4.1.2.2 Salinisation test

The first experiment was conducted at EC = 60m*M* NaCl (about 6 dS/m), three days later salinity was increased to 120m*M* NaCl (12dS/m) (Gregorio *et al.,* 1997). This was done by adding NaCl to the nutrient solution and pH in nutrient solution was always maintained at 5 daily. All the genotypes including checks died within 10 days. This was due to the high temperatures coupled with a dry environment (low relative humidity), which increased stress to the rice genotypes. A preliminary test experiment was therefore established to generate a screening procedure which would allow proper genotype discrimination under the prevailed condition.

During the preliminary test experiment, three setups were tested to standardize the screening system using:

i) application 2 dSm^{-1} after every 24 hours up to a maximum of 6 dSm^{-1} thereafter, maintained until the sensitive check died,

ii) 5 dSm^{-1} was applied and maintained throughout until sensitive check died,

iii) 4 dSm^{-1} was applied and maintained for 3 days and thereafter the concentration was increase to 8 $dSm^{-1}$and maintained until the sensitive check died.

Result from this preliminary experiment showed that a developed salinisation standard using 2 dSm^{-1} after every 24 hours up to a maximum of 6 dSm^{-1} indicated better differences among genotypes and therefore used for screening the material in the study. The study was in a split plot experiment arranged in randomized complete block design with four replications, where the main factors were salt levels and sub factors were genotypes.

4.1.2.3 Data collection

Data collection was done 10 days after the maximum desired stress level was achieved. Plant growth (vigour), injury symptoms, shoot fresh and dry weight, shoot Na^+, K^+ and Na^+/K^+ were determined in both control and salt stressed plants. Scoring for salt tolerance on the basis of seedling vigour and salt injury was done on a scale at a respective growth stage of the plant (IRRI, 1988); where 1 - Germination, 2 - Seedling, 3 - Tillering, 4 - Stem elongation, 5 - Booting, 6 - Heading, 7 - Milk stage, 8 - Dough stage, and 9 - Mature grain. Salt injury rating was done between growth stage 3-4 and was rated as follows 1 = Growth and tillering nearly normal 3 = Growth nearly normal but there is some reduction in tillering and some leaves rolled; 5 = Growth and tillering reduced; most leaves rolled, only a few elongating; 7= Growth completely ceases; most leaves dry; some plants dying; 9 = Almost all plants dead or dying. Seedling vigour was done in stage 2 (IRRI, 1988) of plant development using a scale of 1-9 and rated as follows: 1 = Extra vigorous (very fast growing; plants at 5-6 leaf stage, have 2 or more tillers in majority of the population); 3 = Vigorous (fast growing; plants at 4-5 leaf stage have 1-2 tillers in majority of population); 5 = Normal (plant at 4-leaf stage); 7 = Weak (plants somewhat stunted; 3-4 leaves; thin population; no tiller formation); 9 = Very weak (stunted growth; yellowing of leaves).

Plant shoots were harvested for the determination of Na^+ and K^+ concentrations at 20d after the start of salt stress treatments. Few seedlings were left in the treated solution to understand the maximum survival days for each of the tested genotypes. Harvested plant samples were dried and ground to a fine powder and about 0.1 g was transferred to a test tube containing 10 mL of 0.1 N acetic acid, and heated in a water bath at 80^oC for 2 h as describe by Ansari and Flowers (1986). The extracted tissue was cooled at room temperature and left overnight, and then filtered using Whatman filter paper number 40.

Sodium and potassium concentrations were then determined using an atomic absorption spectrometer.

4.1.3 Screening rice for saline – sodic tolerance (soil based method)

4.1.3.1 The experimental site and climate

The experiment was done in a prepared shade house at the Agriculture Research Institute (ARI) Mlingano - Tanga, Tanzania in 2008. The research institute is located at an altitude of 184 m a.s.l, longitude of 38º 54' E and lattitude of 05º 09' S. Mlingano is humid with a bimodal type of rainfall (1150mm per annum). But during recent years the amount and distribution of rainfall has tended to decrease especially for the past 5 years. The first rains (Masika), come in the month of March to May, with the peak in April, followed by a dry period to mid - October when the second rain season (Vuli) starts. The short rain has its peak in November and begins to decline towards mid-December.

4.1.3.2 Soil samples

The top soil (~15 cm layer) of naturally occurring saline - sodic soil samples were collected from two different rice sites at Mkomazi irrigation scheme in Korogwe district – Tanga region. The soils from site 1 were collected from the area showing plant injury characteristics, whereas soils from site 2 were collected from the field where normal plant growth was observed. Three sub-samples were made from each soil sample and taken to the laboratory for analysis. The pH (1:2 soil/water ratios), sodium adsorption ration (SAR), and electrical conductivity (EC) were determined as described by Richards (1954). A summary of analytical laboratory results are indicated in Table 4.2 below. The three classes of SASs as described by Seelig and Richardson (1991) are saline (EC >4dSm-1, ESP<13%, pH<8.5); saline-sodic (EC >4dSm-1, SAR>13%, pH<8.5) and sodic soils (EC<4dSm-1, ESP>13%, pH>8.5). After the laboratory results the soils were sieved (2mm) before filling in pots of 5 kg capacity for seedling transplanting.

Table 4.2 Laboratory analytical results for saline - sodic soil samples collected for genotype screening

Soil characteristics	Mean values	
	Saline-sodic soil	Un-treated soil
Soil		
pH (1:2 soil water ratio)	9.5	7.20
Org C%	0.56	2.55
Total N%	0.074	0.28
Exchangeable bases		
Mg	2.49	1.77
Ca	2.41	2.88
Na	50.20	0.39
Ec (dS m-1) (1:2 soil water ratio)	4.2	0.41
SARa	31.4	0.26

$SAR = Na/(((Ca+Mg)/2)^{1/2})$

Salt injury was rated as indicated in section 4.1.2.3 a per IRRI (1988) standard evaluation system. Tillering ability was assessed at stage 5 of rice plant growth and rated as follows: 1 = very high (more than 25 tillers/plant) 3 = Good (20/25 tillers/plant), 5 = Medium (10-19 tillers/plant) 7 = Low (5-9 tillers/plant) and 9 = very low (less than 5 tillers/plant) (IRRI, 1988). Spikelet fertility was recorded at stage 9 of rice plant growth and filled grains per spikelet were estimated in percentage and rated, where 1 = highly fertile (>90%), 3 = fertile (75-89%), 4 = partly sterile (50-74%), 7 = highly sterile (<50% to trace) and 9 = (0%) (IRRI, 1988). Well developed 100 grains were weighed in grams on a precision balance at 14.4% moisture content and converted to 1000 grain weight.

4.1.4 Data treatment and statistical analysis

All the data were tested for normality and the parameters were submitted for analysis of variance (ANOVA) with two levels of classification (salinity and genotype). Data were analyzed using GENSTAT release 11 (Payne *et al.,* 2008) computer package. Analysis of variance (ANOVA) was performed to determine statistically significant differences among genotypes, salinity levels, and their interactions. Simple linear correlation coefficients were calculated to establish relationships between physiological attributes of genotypes under salinity.

4.2 Results and discussion

4.2.1 Genotype performance in hydroponics screening method

Loss of plant turgidity was observed immediately after salt imposition in treated solution. Less turgidity loss was observed in tolerant checks Pokkali and IR 67076-2B-21-2 and slightly less turgidity loss was observed in a local cultivar TXD 306; this was probably due to its highly vigorous growth therefore less salt accumulation and effects in plant tissues. Previously, Munns (2002) reported that saline solutions impose both ionic and osmotic stresses on plants. Yeo and Flowers (1989) reported the importance of vigorous growth at early stages of plant development. They reported that vigorous growth provides a dilution effect of the salts concentration in plant tissues therefore increases survival of the plant under saline condition.

The genotypic variability for salinity tolerance was assessed and expressed as less salt injury symptoms, low Na^+ accumulation and Na^+/K^+ ratio in plant tissues and high biomass accumulation (fresh weight and dry weight). The analysis of variance (ANOVA) indicated that genotypes and salinity effects and their interactions were significant ($P < 0.001$) for all plant characteristics (Table 4.3). At both salt levels, mean performance of all the traits measured also showed significant ($P < 0.001$) difference among genotypes. Salinity x genotype interaction indicated that genotypes responded differently to saline stress. Rice cultivar seedlings responses were different among genotypes in both salt levels.

In general saline stress significantly increased Na^+ accumulation in plant tissues, decreased K^+ absorption resulted in narrower Na^+/K^+ ratio, increased leaf injury symptoms and reduced seedling biomass accumulation in almost all the tested genotypes as compared to the non-saline environment (Table 4.4 and 4.5). However, a significant interaction observed for all the traits indicates that there was differential performance between genotypes under different salt environments for all the traits measured. These results indicated that genetic variability exists among the genotypes in terms of the parameters measured and gotypes behaved differently in treated and non-treated solutions. The study therefore, highlights that the traits could be used as selection criteria for salt tolerance at early growth stages of rice plant, however selection should be done under individual salt condition.

Table 4.3 Mean squares for various traits of rice genotypes under saline and non-saline nutrient solution

Source of variation	d.f.	Mean Squares						
		%K	%Na	Na/K	Survival	Plant Vigour	Fresh weight	Dry weight
Rep	3	0.23	0.24	0.004	0.73	0.09	0.03	0.006
Salt Level (S)	1	165.4***	25.7***	0.20***	351.5***	311.6***	26.6***	1.36***
Error (A)	*3*	*0.28*	*0.18*	*0.009*	*0.73*	*0.09*	*0.08*	*0.005*
Genotype (G)	9	3.4***	1.18***	0.034***	14.7***	15.8***	2.06***	0.11***
G x S	9	3.6***	1.14***	0.011*	14.7***	15.8***	0.23*	0.03***
Error (B)	*54*	*0.32*	*0.10*	*0.003*	*0.4*	*0.34*	*0.09*	*0.005*

****, * =highly significant at P< 0.001 and significant at p<0.05, respectively.*

Studies have reported similar decreasing trend on measured plant characteristic from control to saline treated media in rice (Singh, 2001; Moradi *et al.,* 2003; Mahmood *et al.,* 2004), in wheat (Munns *et al*., 2006) in sorghum (Krishnamurthy *et al.,* 2007), in brassicaceae (Ashraf and Sarwar, 2002), in grapevine (Shani and Ben-Gal, 2005).

4.2.2 Genotypes performance under saline environment

4.2.2.1 Shoot Na^+ and K^+ concentration and Shoot Na^+ / K^+ ratio

The differences among the genotypes and salinity levels and their interactions were significant for shoot Na^+ and K^+ concentration and shoot Na^+/K^+ (Table 4.3). Analysis of shoot ion content showed that all the genotypes had increased levels of Na^+ and differential performance was observed in some genotypes under saline and non-saline conditions. Genotypes IR 56, Pokkali and IR67076-2B-21-2 performed well under treated solution by having minimum Na^+ accumulation in plant tissue. The rest of genotypes, for example, Gigante, IR 64 and Thailand performed well under control condition by having less shoot Na^+ concentration but performed poorer under saline condition (Figure 4.2). Geno CSR 27 performed poorly than the rest of genotypes. On the basis of less than 50%

reduction in shoot Na^+ concentration, better performing genotypes were the tolerant checks (Pokkali, IR67076-2B-21-2) and a local cultivar IR 56 (Table 4.4).

All the tolerant genotypes had comparatively less sodium uptake than the sensitive ones. Except for a local cultivar IR 56 which also showed good performance even more than the checks, all other local cultivars performed poorly in comparison to susceptible check (IR 29). The highest Na^+ uptake was recorded in Gigante and IR 64 which was closely followed by Thailand and IR 29. The rest of the genotypes formed the medium group regarding Na^+ uptake. In their studies Mishra *et al.* (2001) and Munns (2002) also reported similar results and showed that Na^+ is a highly damerging element in plant tissue and absorbed more under salt stress environment.

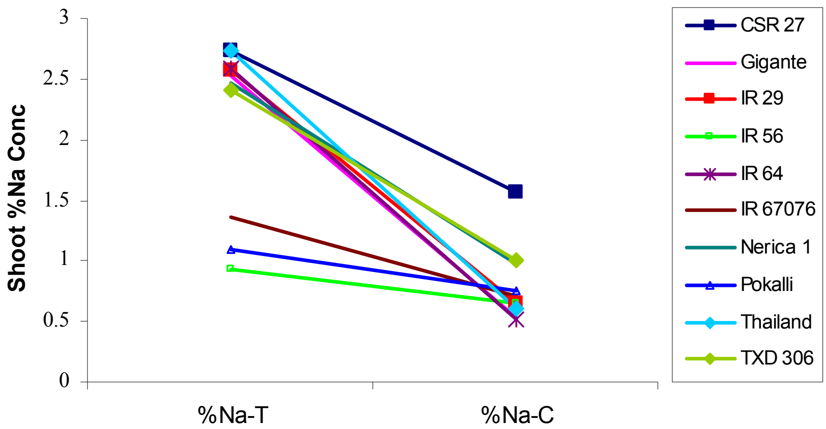

Figure 4.2 Changes in shoot %Na concentration of rice genotypes under saline treated (%Na-T) and non-treated (%Na-C) solution.

The trend for K^+ was the reverse to that of sodium; it decreased with the increase in salinity (Figure 4.3). The result showed that, increase in shoot Na^+ concentration concomitantly decreased shoot K^+ concentration. Minimum reduction in K^+ uptake under saline condition was noted in CSR 27 followed by TXD 306 and Pokalli, other genotypes having higher reduction in K^+ uptake than the control. However all the rice genotypes (except IR 64, Thailand and a susceptible check IR 29) maintained less than 50 % reduction in K^+ (Table 4.4). The study also indicated that, increasing uptake of Na^+ causes low K^+ uptake which results in increasing Na^+/K^+ ratio in the plant shoot.

Table 4.4 Mean shoot Na^+, K^+ concentrations and Na^+/K^+ ratio in rice genotypes under salinized (6 dSm^{-1}) condition.

Genotypes	$\%Na^+$ conc.			$\%K^+$ conc.			Na^+/K^+		
	Treated	Control	% Increase	Treated	Control	% decrease	Treated	Control	% Increase
CSR 27	2.74	1.57	42.7	5.70	6.48	12.1	0.30	0.18	41.5
Gigante	2.53	0.53	79.1	4.66	7.96	41.4	0.33	0.11	65.3
IR 29	2.57	0.65	74.7	4.23	9.35	54.7	0.37	0.15	60.8
IR 56	0.93	0.65	30.1	4.61	7.14	35.5	0.11	0.08	25.6
IR 64	2.59	0.52	79.9	4.20	9.81	57.2	0.34	0.12	63.4
IR67076-2B-21-2	1.36	0.71	47.8	5.80	9.73	40.4	0.21	0.12	40.9
Nerica 1	2.47	0.97	60.7	4.55	7.40	38.5	0.46	0.20	55.8
Pokkali	1.10	0.76	30.9	4.89	7.39	33.8	0.12	0.09	20.9
Thailand	2.73	0.61	77.6	3.49	7.93	56.0	0.49	0.20	59.7
TXD 306	2.41	1.01	58.9	4.70	6.38	26.3	0.37	0.17	54.6
Sed		*0.23*			*0.41*			*0.04*	
$Lsd_{0.05}$		*0.46*			*0.82*			*0.08*	

Note: Decrease or increase (%) = (Value of control plant -value of treated)/ value of control) x 100)

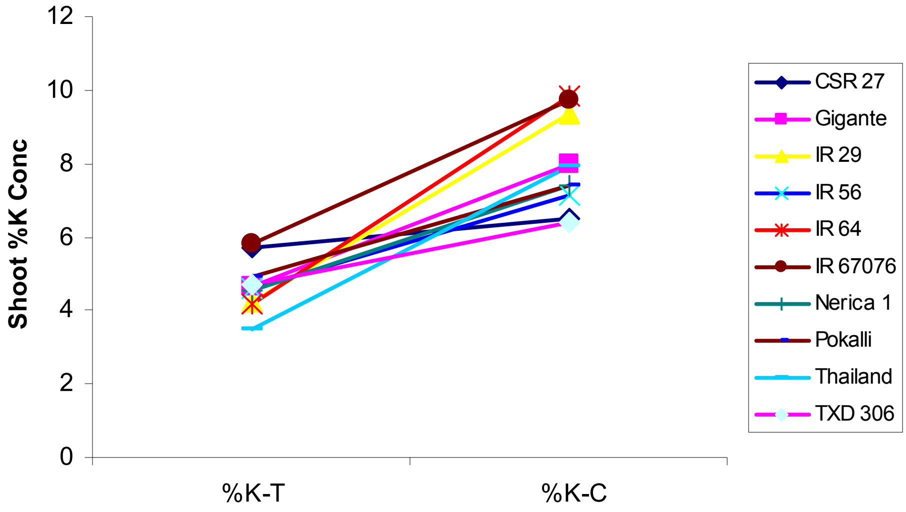

Figure 4.3 Changes in shoot %K concentration of rice genotypes under saline treated (%K-T) and non-treated (%K-C) solution.

Genotypes with higher Na^+ concentrations also showed a decreased leaf K^+ concentration resulting in an increase in Na^+/K^+ ratio. There is therefore an indication of some inhibition effect on K^+ absorption under saline environments. The check genotype Pokalli had the lowest change in Na^+/K^+ between treated and non treated solution followed by IR 56. A greater change was obsesved in Gigante and the poorest performance was observed in Nerica 1 (Figure 4.4). Genotypes Pokalli and IR67076-2B-21-2, CSR 27 and a local cultivar IR 56 had maintained the minimum Na^+ tissue concentration, therefore narrower Na^+/K^+ ratio and minimum reduction of less than 50% (Table 4.4). This suggests that these genotypes are capable of taking up more K^+ under salt stress to maintain superior Na^+/K^+ balance in the shoot.

Similar observations were reported by Mishra *et al.* (2001). Blaha *et al.* (2000) reported that high Na^+/ K^+ ratio can disrupt various enzyme processes in the cytoplasm. Devitt *et al.* (1981) added that increase in Na^+ concentration in growing plants create Na^+/K^+ imbalance which adversely affects grain yield. According to Bhandal and Malik (1988), metabolic toxicity of Na^+ is largely a result of its ability to compete with K^+ for binding sites essential for cellular function. More than 50 enzymes are activated by K^+, and Na^+ cannot substitute this role. In this case, the use of Na^+ and Na^+/ K^+ ratio was taken into consideration as a useful characteristic while screening the lines

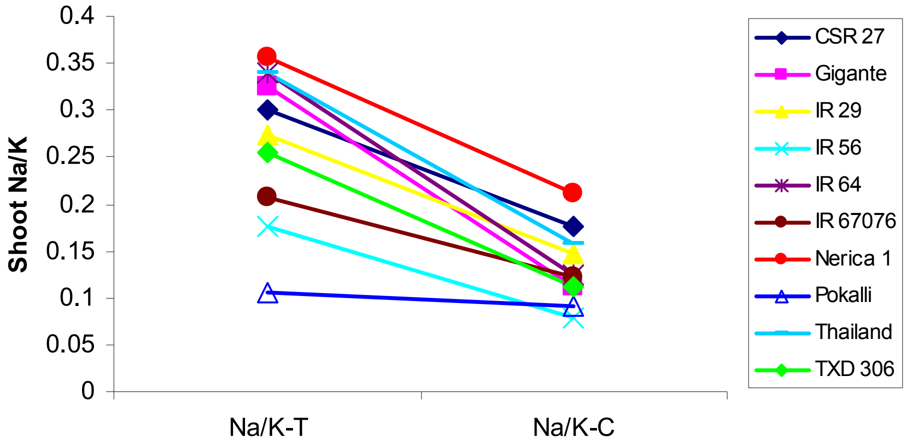

Figure 4.4 Changes in shoot Na^+/K^+ ratio of rice genotypes under saline treated (Na/K-T) and non-treated (Na/K-C) solution.

4.2.2.2 Plant vigour and injury symptoms

The growth observations recoded at seedling stage showed that there was a significant liner decrease and increase in plant vigour and injury symptoms, respectively from non-treated to treated solution (Figure 4.5). Plants exhibited symptoms of salt injury symptoms 7- 10 days after treatment. Significant variation on plant injury was observed among genotypes whereby the tolerant checks (Pokalli, IR67076-2B-21-2, CSR 27) and a local cultivar TXD 306 showed less injury and nearly normal growth than the rest of genotypes. During the study it has been observed that salt injury started with reduction in effective leaf area (Figure 4.5 & 4.6).

Among the measured characters, plant vigour was more affected than the rest of the traits as most of the genotypes had > 50% reduction in vigour (Table 4.5 and 4.6). Only genotype Pokalli (a saline tolerant check) and TXD 306 (a local cultivar with high vigour characteristics) performed better by having < 50% reduction in vigour when compared to the control. Maximum reduction was observed in genotypes IR 29 (a susceptible check), Nerica 1 and IR 64.

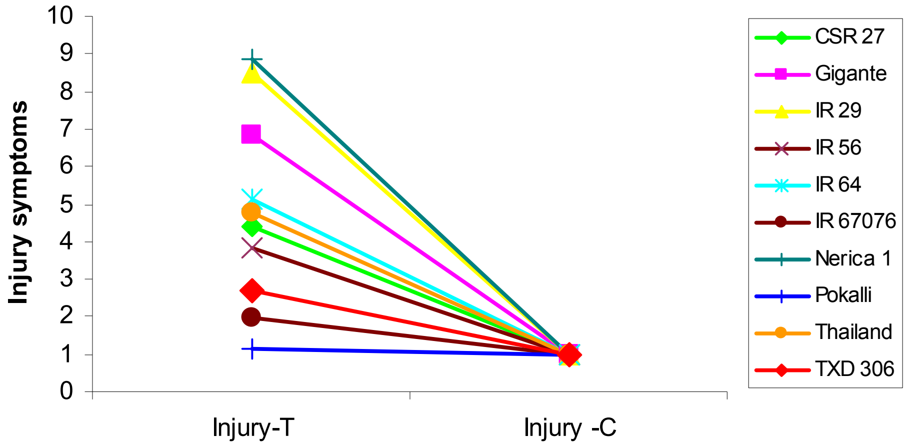

Figure 4.5 Changes in shoot injury symptoms of rice genotypes under saline treated (Injury-T) and non-treated (Injury-C) solution.

Early vegetative vigour is important as it is associated with various combinations of rapid seedling emergence, early development, heavy tillering, and rapid increase in seedling height. Richards (1992) highlighted that breeding for more vigorous plants has been argued to be agronomically the most effective approach for increasing yield in saline soils. Furthermore, Acquaah, (2007) reported that although heritability of early vigour is low, evaluation and selection can definitely result in measurable breeding advance. The oldest leaves started to roll followed by the next older, and so on. Finally, the survivors had the old leaves losing vitality with the youngest remaining green. All the genotypes showed minimum Na^+, low Na^+/K^+ ratio and high vigour and had also low leaf injury symptoms. Maximum injury symptoms were observed in Nerica 1 and IR 29 and only genotype Pokalli and IR67076-2B-21-2 (saline tolerant checks) showed less injury symptoms and had <50% reduction on injury symptoms (Table 4.5).

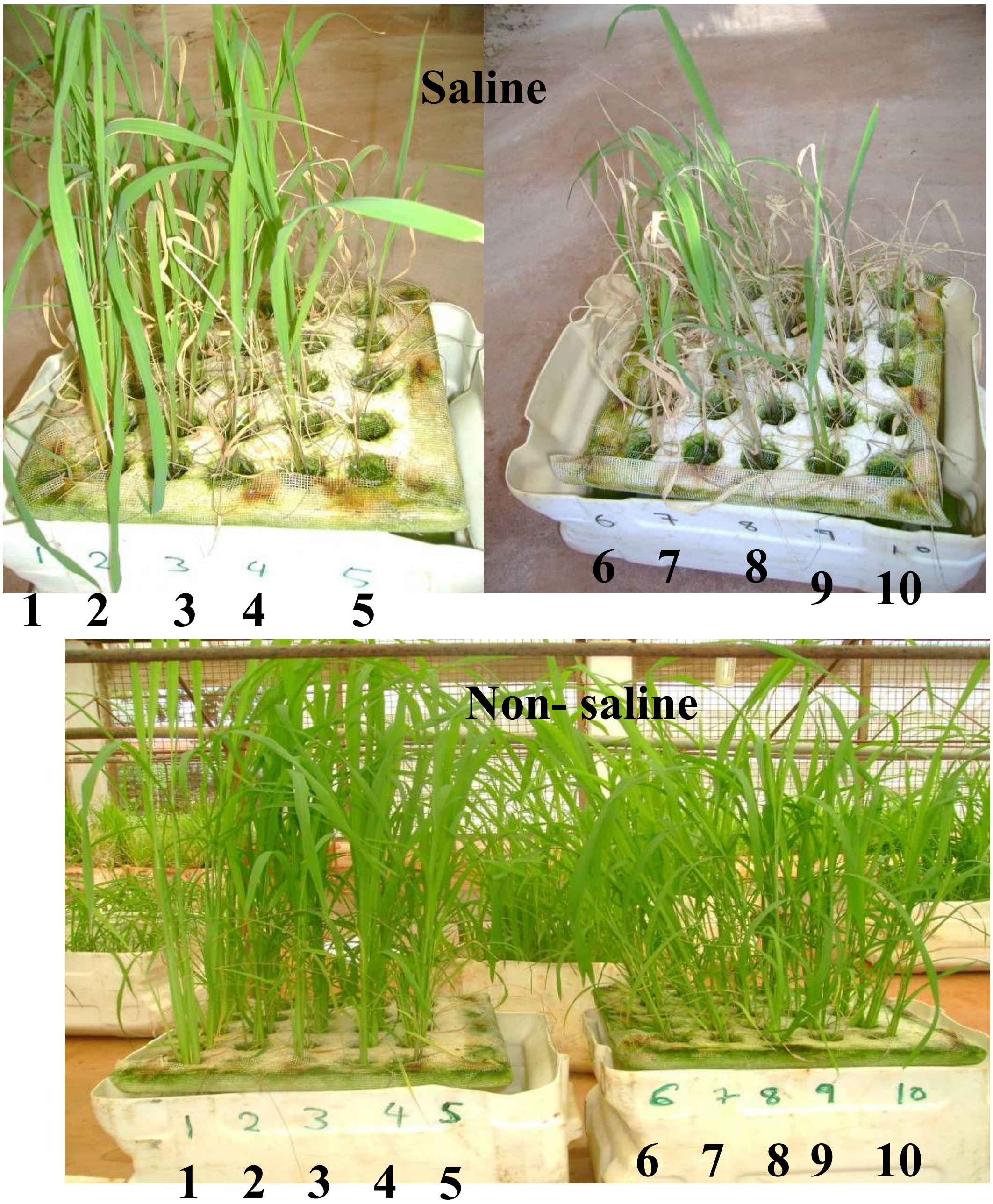

Figure 4.6 Plant injury symptoms of genotypes under saline and non-saline nutrient solution

(1 = Pokkali, 2 = IR67076-2B-21-2, 3 = CSR 27, 4 = TXD 306, 5 = IR 64, 6 = Nerica 1, 7 = Gigante, 8 = IR 56, 9 = Thailand and 10 = IR 29 - a susceptible check).

Table 4.5 Mean plant injury, vigor and biomass in rice genotypes under salinized (6 dSm^{-1}) condition.

	Plant Injury (Rated 1-9)[1]			Plant vigour (Rated 1-9)[2]			Fresh wt (g)			Dry wt (g)		
Genotype	Treated	Control	% change	Treated	Control	% change	Treated	Control	% change	Treated	Control	% change
CSR 27	4.5	1	77.8	2.3	1	56.5	0.87	1.65	47.2	0.22	0.52	57.7
Gigante	6.9	1	82.9	6.3	1	84.1	0.85	2.32	63.3	0.30	0.67	55.2
IR 29	8.5	1	88.2	8.5	1	88.2	0.35	1.34	73.8	0.10	0.55	81.8
IR 56	3.9	1	74.0	7.9	1	87.3	0.72	1.31	45.0	0.28	0.51	45.0
IR 64	6.2	1	83.7	5.3	1	81.1	0.53	1.38	61.6	0.15	0.41	63.4
IR67076-2B-21-2	2.0	1	49.2	2.3	1	56.5	0.86	1.66	48.2	0.21	0.48	56.2
Nerica 1	8.7	1	88.5	7.3	1	86.3	0.72	2.04	64.7	0.20	0.69	71.2
Pokkali	1.2	1	13.0	1.2	1	16.7	1.83	2.70	32.2	0.60	0.76	21.1
Thailand	5.7	1	82.3	6.6	1	84.8	0.69	1.53	54.9	0.29	0.49	40.8
TXD 306	5.7	1	82.4	1.8	1	44.4	0.98	1.95	49.8	0.29	0.58	50.0
Sed		0.43			0.40			0.22			0.23	
$Lsd_{0.05}$		0.87			0.82			0.44			0.09	

Note: Decrease or increase (%) = (Value of control plant -value of treated)/ value of control) x 100)

[1]Salt injury rating:1= Growth and tillering nearly normal; 9 = Almost all plants dead or dying

[2]Seedling vigour:1 = Extra vigorous (very fast growing; plants at 5-6 leaf stage, have 2 or more tillers in majority of the population); 9 = Very weak (stunted growth; yellowing of leaves).

4.2.2.3 Shoot fresh and dry weights

A significant variability among rice genotypes was observed in terms of shoot fresh and dry weight. A significant decrease in shoot fresh weights was observed under saline stress compared to the control. Analysis of shoot dry weight also showed a significant linear decrease and differential performance was observed among some genotype under saline and non-saline condition (Figure 4.7). On the basis of less than 50% reduction in shoot fresh weight, superior performances were observed in Pokkali followed by IR 56, CSR 27, IR67076-2B-21-2 and TXD 306. Minimum shoot fresh weights accumulations were observed in IR 29 and Nerica 1 (Table 4.5). Reduction in biomass accumulation under saline conditions has also been reported in earlier studies (Mishra *et al.*, 2001; Blaha *et al.*, 2000; Farshadfar *et al.*, 2007). Once the concentration of Na^+ and Cl^- in the leaf causes a growth reduction, then there is less material into which additional salt can be distributed resulting into leaf injury and finally plant death (Farshadfar *et al.*, 2007).

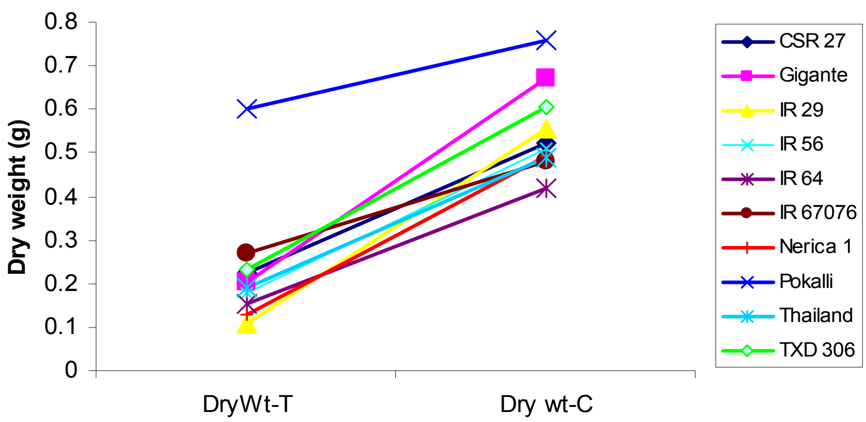

Figure 4.7 Changes in shoot dry weight of rice genotypes under saline treated (DryWt-T) and non-treated (DryWt-C) solution.

The comparison regarding shoot ion concentration and growth parameters among the genotypes (Table 4.6) clearly indicated that genotype Pokkali maintained all the seven recorded parameters by having less than 50 % reduction over the control, therefore rated highly tolerant. This genotype survived longer (37d) under salinized conditions compared to all the tested materials. Pokkali was followed by IR67076-2B-21-2 which maintained five out of seven parameters and rated tolerant. Genotype IR67076-2B-21-2 had equal survival rate, injury symptoms and vigour similar to those of Pokkali (Figure 4.6), but had less survival days and relatively low dry matter accumulation. The two checks genotypes were followed by IR 56 which successfully maintained four out of eight parameters and therefore rated slightly tolerant. Among the local genotypes tested, IR 56 showed significantly more superior survival and less injury than the rest. This genotype appears third after Pokkali and IR67076-2B-21-2 in terms of survival rate and injury but had significantly lower survival days, vigour and biomass accumulation than the two checks. The poorest performance was noted in the case of IR 64 and Nerica1 which did not perform well in any of the characters measured therefore rated highly susceptible.

Table 4.6 Rice genotypic performance calculated on the basis of less than 50 % reduction in the character measured under saline condition.

	Characters								
Genotype	Injury	Vigour	% Na	% K	Na/K	Fresh wt	Dry wt	No of variables	Rating
CSR 27	-	-	+	-	+	+	-	3	S
Gigante	-	-	-	-	-	-	-	0	HS
IR 29	-	-	-	-	+	-	-	1	HS
IR 56	-	-	+	+	+	+	-	4	ST
IR 64	-	-	-	-	-	-	-	0	HS
IR67076-2B-21-2	+	-	+	-	+	+	+	5	T
Nerica 1	-	-	-	-	-	-	-	0	HS
Pokkali	+	+	+	+	+	+	+	7	HT
Thailand	-	-	-	-	+	-	+	2	S
TXD 306	-	+	-	-	-	+	+	3	S

Note: + = Less than 50 % reduction over control, - = More than 50 % reduction over control
HT = Highly tolerant, T = Tolerant, ST = Slightly tolerant, HS = Highly sensitive ; S = Sensitive

4.2.2.4 Association of characters

In the present study association of characters was investigated under both salinized and control solutions, but only the results on association of characters under saline solution were presented in Table 4.7. Under control solution only significant and positive associations were observed between fresh weight and dry weight ($r = 0.39^{**}$; $P=0.01$); between %Na^+ and Na^+/K^+ ($r = 0.88^{***}$; $P<0.001$), and significant negative associations was observed between dry weight and Na^+/K^+ ratio ($r = -0.34^{**}$; $P=0.01$). The rest of the traits did not show any significant association. Under saline treated solution, there was a strong negative association of all the growth parameters with the Na^+ and Na^+/K^+ ratio, indicating the negative effects of increasing Na^+ concentration and Na^+/K^+ ratio on biomass accumulation under saline conditions. Although associations between K^+ and growth parameters were significant only for plant vigour, a weak positive relationship between K^+ with shoot fresh and dry weight were still observed (Table 4.7). This indicates the enhancement of K^+ towards biomass accumulation in the plant under such environments.

Table 4.7 Phynotypic correlation coefficients of symptomatic and growth attributes of NaCl grown rice genotypes with shoot ionic content (n=10).

Plant Characteristics	**%K$^+$**	**%Na$^+$**	**Na$^+$/ K$^+$**	**DW**	**FW**	**PI**
%K$^+$	1					
%Na$^+$	-0.34*	1				
Na$^+$/ K$^+$	-0.24*	0.88***	1			
Dry weight (DW)	0.14ns	-0.49**	-0.34**	1		
Fresh weight (FW)	0.25ns	-0.37**	-0.23*	0.82***	1	
Plant Injury (PI)	-0.08ns	0.62***	0.35**	-0.54***	-0.60***	1
Plant Vigor (PV)	0.29*	-0.45**	-0.30*	0.55***	0.65***	-0.84***

***,** , *and ns = significant at 0.1%, 1%, 5% and not significant

Krishnamurthy *et al.* (2007) reported similar findings on weak association of shoot K^+ concentration with biomass accumulation. Plant injury showed a strong positive relationship with Na^+ and Na^+/K^+ ratio, but a weak and negative one with K^+ and the K^+/Na^+ ratio, as has been observed in rice (Mahmood *et al.*, 2004), green gram (Misra and Dwivedi, 2004) and other crops (Farshadfar *et al.*, 2007). This confirms the detrimental effect of high Na^+ concentrations in the plant tissues. A highly significant positive correlation coefficient was found between plant vigour and shoot fresh weight, shoot dry weight and K^+ concentration in plant. On the other hand significant inverse associations were observed between plant vigour and plant injury, shoot Na^+ concentration and Na^+/K^+ ratio. Studies have reported similar inverse associations between Na^+ and $Na/^+K^+$ on survival and biomass accumulation in the plant, for example in cowpea genotypes (Murillo-Amador et al., 2002) in green gram (Misra and Dwivedi, 2004), in barley (Farshadfar *et al.*, 2007) and in sorghum (Krishnamurthy et al., 2007). This indicates that a more vigorous and less injured the plant, increases the chance to survive, grow and accumulate high biomass under salt stress environment.

4.2.3 Genotype performance under saline – sodic soil environment

4.2.3.1 Plant growth parameters under different levels of saline-sodic soil

Thirty days after seedling transplanting in saline-sodic affected soil and normal soil, severe effects of salt were immediately seen in rice plants grown in saline-sodic soil, where growth was significantly arrested in almost all genotypes. A decrease in plant height and plant vigour was clearly observed. The emerging leaf blades were tightly rolled stunted and the tips were severely withered. The symptoms appeared mostly in older leaves and the upper portions of the leaves rolled in and were necrotic. However, the younger leaves of the affected plant remained succulent and plants looked dark green. Statistically, except number of tillers per plant which had significant interaction at P = 0.05, genotypes, salt levels and their interactions were highly significant ($p<0.001$) on all measured parameters (Table 4.8).

Table 4.8 Mean squares for some growth and yield parameters of rice Genotypes at vegetative and reproductive growth stages

Parameters	Source of variation		
	Genotype (G) (df=10)	Salt Levels (S) (df=1)	Interactions (GxS) (df=10)
At vegetative stage			
Plant injury	0.73***	107.1***	0.73***
No of tillers	3.36***	30.9***	1.06*
Plant height	1269.9***	20122.3***	473.5***
At reproductive stage			
Spikelet fertility	3.08***	383.1***	3.08***
Grains / panicle	2544.1***	45714.0***	900.0***
1000grain wt	150.7***	566.1***	19.7***

*, and *** significant at 5% and 0.01% probability level respectively.

The significant main effects and interaction effects indicated that the genotypes were different and environments were diverse. This implies that genotypes are highly variable and their responses to the different environment also changed. Therefore, genotypes selection can be done on the basis of their performance in specific soil conditions.

4.2.3.2 Leaf injury, tillering and plant height

Significant differences among genotypes for these parameters were observed under saline-sodic stress compared to the control (Table 4.9). On the basis of less than 50% reduction in shoot injury symptoms, better performing genotypes were only a sodic tolerant check CSR 27 and Nerica 2. These genotypes had less leaf injury than the rest. The highest injuries were observed in Pokkali, Thailand and TXD 306. The study also established that salt stress causes detrimental effects on rice leaves, with greater injuries on sensitive genotypes reducing photosynthetic area of the plant, therefore reduce growth and assimilate accumulation to fill the grain that is set and eventually reduce grain yield.

A differential performance on number of tillers was observed under control and treated soil. More tillers per plant were observed under control condition with the highest in IR 64, Kisegese and IR 67076-2B-21-2 showing an average range of 3 to 4 indicating good (20/25 tillers/plant) tillering ability. The rest of the genotypes had average rating between 5 and 6 indicating medium tillering (10-19 tillers/plant). Reduction of tillering ability was observed in the saline-sodic stress condition whereby Kisegese had poor tillering ability, followed by Pokkali and Nerica 1. These genotypes had average rating of 9 = very low tillering (less than 5 tillers/plant). On the other hand, less tillering reduction was observed in genotypes CSR 27, Getu (tolerant checks for sodicity) and a local cultivar Thailand. On the basis of less than 50% reduction in tillering ability, the worst genotypes were Kisegese, IR 64 and IR 67076-2B-21-2. The rest of genotypes showed less than 50% reduction in tillering ability. Significant reductions in plant height were also observed for all genotypes tested. The highest reductions of about two fold were observed in Kisegese, Nerica 1 and Pokkali where as IR 56, CSR 27 and IR 64 showed the lowest plant height reduction (Table 4.9).

This study indicates that in the presence of saline – sodic conditions both plant height and tillering ability were highly reduced. This could be due to the reason reported earlier that high concentration of soluble salts increase the osmotic pressure and decrease the osmotic potential of soil solution which means that the soil water is held with extra energy due to the presence of salts. In addition, the detrimental effects of salt on rice plant reducing

Table 4.9 Evaluation of Plant injury symptoms, number of tillers and plant height in rice genotypes under saline – sodic condition.

	Plant characteristics								
	Injury(Rated 1-9)[1]			Tillering[2]			Plant height		
Genotype	Treated	control	% change	Treated	Control	% change	Treated	control	% change
CSR 27	1.78	1	43.7	5.13	4.68	8.8	63.3	89.0	28.9
Getu	3.00	1	66.7	5.50	5.00	9.1	46.0	71.8	35.9
IR 56	3.35	1	70.1	6.53	4.15	36.4	65.7	77.3	15.0
IR 64	3.68	1	72.8	7.00	3.00	57.1	52.3	72.8	28.2
IR67076-2B-21-2	3.00	1	66.7	7.98	3.85	51.7	32.5	93.5	65.2
Kisegese	3.00	1	66.7	8.75	3.83	57.5	20.2	97.9	79.4
Nerica 1	3.35	1	70.1	8.50	6.35	33.1	31.2	80.4	61.2
Nerica 2	1.91	1	47.7	7.53	5.75	23.6	70.7	107.3	34.8
Pokkali	4.00	1	75.0	8.68	6.00	25.1	60.5	130.5	53.7
Thailand	3.83	1	73.9	6.18	4.83	21.9	71.5	113.2	36.8
TXD 306	3.68	1	72.8	7.18	4.35	25.4	45.6	83.5	45.4
Sed		*0.3*			*0.43*			*9.93*	
Lsd		*0.6*			*0.85*			*19.7*	

Note: Decrease or increase (%) = (Value of control plant -value of treated)/ value of control) x 100)

[1]Salt injury rating:1= Growth and tillering nearly normal; 9 = Almost all plants dead or dying

[2]Tillering ability assessed as: 1 = very high (more than 25 tillers/plant); 9 = very low (less than 5 tillers/plant)

photosynthetic area of the plant, means there is reduction in growth and tillering ability. Ashraf and Harris (2004) also reported that under salt stress environments the plant would have to spend extra energy to get water from the salty soil solution and water uptake and plant transpiration would be reduced, therefore the plant could not be able to meet the energy requirements, resulting in reduced growth.

However, some genotypes can still have less reduction in their growth and tillering ability, and therefore recommended as suitable under such salt stress environments. Reduction in plant tillering and height with increasing salinity and sodicity concentration in the soil has also been reported in several studies (Zeng *et al.*, 2001; Mahamood *et al.,* 2004). Zeng *et al.* (2001) observed a significant reduction in tiller number per plant when rice plants were salinized for 20 days.

4.2.3.4 Spikelet fertility, grains per panicle and 1000-grain weight yield

Saline-sodic characteristics significantly reduced the seed yield per plant. The observations recorded at maturity showed that saline-sodic conditions significantly ($p<0.001$) depressed spikelet fertility, grains per panicle and 1000 grain weight for all tested materials. There was linear decrease in all the yield parameters from the control to saline – sodic soil conditions (Table 4.10). All genotypes except Getu and Kisegese, had high spikelet fertility and rated 1.00 (highly fertile - >90%) under normal soil. High spikelet sterility was observed in Getu and Kisegese under control soil condition. Getu was the sodic tolerant check known to grow well under high sodicity and pH environments. However, the poor performance of Getu was linked to its high level of brown leaf spots symptoms observed in the two genotypes. Both Getu and Kisegese had high level of brown leaf spot symptoms and the genotypes showed high K^+ deficiency symptoms. Although these problems were corrected, the two genotypes showed to be more affected than the rest. The problem showed to be increasing from panicle emergence to maturity.

Table 4.10 Mean spikelet fertility, number of grains per panicle and 1000 grain weight in rice genotypes under saline – sodic condition.

	Plant characteristics								
	Spikelet fertility[1]			No of grains/panicle			1000 grain wt		
Genotypes	Treated	Control	% change	Treated	Control	% change	Treated	Control	% change
CSR 27	1.13	1	11.1	119.3	144.2	17.2	14.9	22.4	33.20
Getu	8.50	4	52.9	70.8	121.5	41.7	16.2	18.6	12.83
IR 56	5.68	1	82.4	85.2	143.6	40.7	14.1	21.5	34.33
IR 64	5.35	1	81.3	56.3	131.7	57.2	19.4	22.7	14.42
IR67076-2B-21-2	3.85	1	74.0	46.2	104.4	55.8	12.5	15.5	19.68
Kisegese	7.00	3	57.1	30.3	98.3	69.2	9.8	20.7	52.54
Nerica 1	5.35	1	81.3	60.5	139.7	56.7	9.6	19.9	51.69
Nerica 2	1.95	1	48.7	108.5	148.2	26.7	25.2	27.0	6.38
Pokkali	5.53	1	81.9	90.4	120.6	25.1	22.3	23.6	5.60
Thailand	2.35	1	57.4	86.0	125.9	31.7	15.3	24.2	36.82
TXD 306	5.83	1	82.8	80.4	178.3	54.9	25.1	28.3	11.39
Sed		*0.33*			*6.4*			*1.11*	
Lsd		*0.66*			*12.7*			*2.21*	

Note: Decrease or increase (%) = (Value of control plant -value of treated)/ value of control) x 100)

[1]Spikelet fertility was assessed as filled grains per spikelet and estimated in percentage and rated as1 = highly fertile (>90%), 7 = highly sterile (<50% to trace) and 9 = (0%)

Under saline-sodic soil CSR 27 and Nerica 2 had the average rating of 1 to 2 indicating >90% spikelet fertility, followed by Thailand and IR 67076-2B-21-2 which had an average rating of 3 and 4, respectively, indicating 75-89% spikelet fertility. These genotypes also showed superior performance by having less than 50% reduction in spikelet fertility. Genotypes Getu and Kisegese, had the highest level of sterility and rated 7 to 8 which indicated < 50% spikelet fertility. The study results revealed that spikelet fertility was a more highly affected trait under saline-sodic conditions than any other trait (Table 4.11), indicating that it will be useful criterion for selection of the materials under salt stress conditions. According to Mishra *et al.* (2006), sterility is normal in rice and high yields in rice are obtained with normal spikelet sterility of as much as 10 to 15%. Their study also reported increasing spikelet fertility under high salinity environment and reported that high percentage of spikelet sterility relates to a low level of salt tolerance.

Number of grains per panicle differed significantly between genotypes within soil condition and between salt levels (Figure 4.8). Under normal soil conditions a greater number of grains per panicle were observed in TXD 306. This variety showed a significantly more grains per panicle compared to the rest of the genotypes. However, its grain yield per panicle was extremely reduced under salt stress compared to the rest of the genotypes. Under salt stress condition, CSR 27, Nerica 2 and Pokalli showed low reduction on number of grains produced per panicle, followed by Thailand, IR 56 and Getu. In terms of less than 50% reduction over control, maximum reduction was recorded in Kisegese and IR 64, followed by Nerica 1, IR 67076-2B-21-2 and TXD 306. The other genotypes showed < 50% reduction in number of grain per panicle; however their reductions were more than of CSR 27 (Figure 4.8).

A significant difference ($P<0.001$) between genotypes within and between salt level were also observed on 1000 grain weight. All genotypes showed a severe reduction in seed weight under saline-sodic conditions compared to the control. Under control condition, high seed weights were observed in TXD 306, Nerica 2 and Thailand, and low seed weights were observed in IR 67076-2B-21-2, Nerica 1 and Getu (Figure 4.9). However, under saline-sodic environment, superior genotypes were, Nerica 2, TXD 306 followed

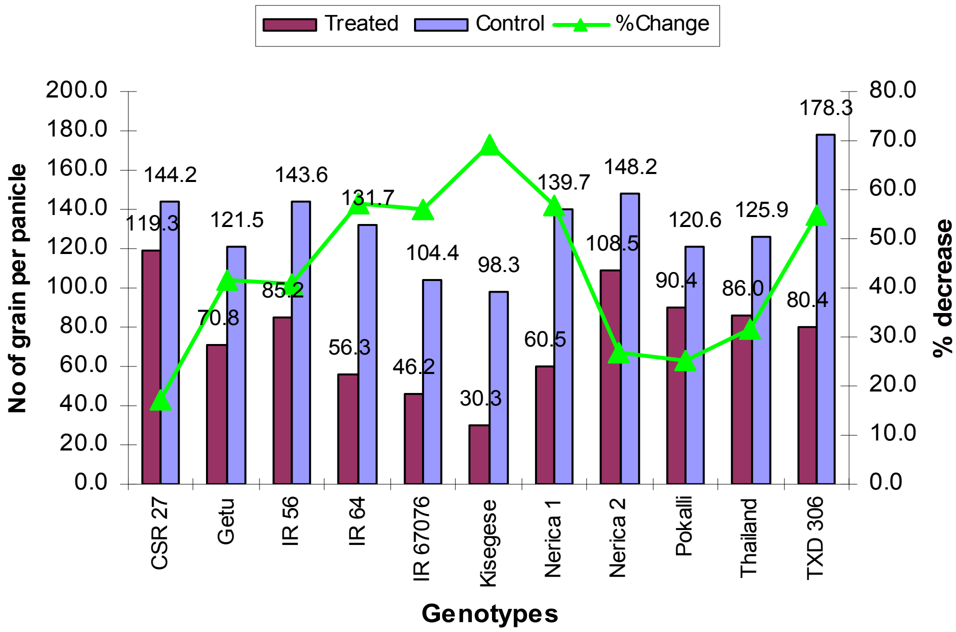

Figure 4.8 Changes in number of grains per panicle of rice genotypes under control and saline-sodic conditions.

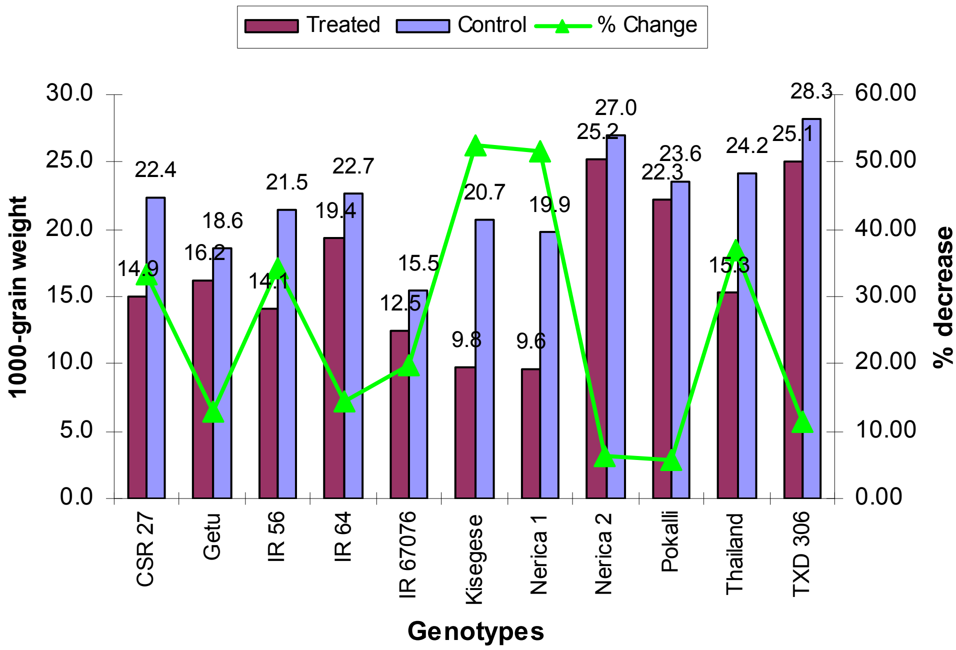

Figure 4.9 Changes in number of grains per panicle of rice genotypes under control and saline-sodic conditions.

by Pokkali and the poorest were Kisegese and Nerica 1. Less than 50% reduction over the control was recorded in all the genotypes except Kisegese and Nerica1. However, less reduction in seed weights were observed in Nerica 2 and Pokkali which had 5 and 6% reduction, respectively, over the control indicating their superior performance over the rest of the genotypes (Figure 4.9).

The comparison regarding growth and yield attributes among genotypes under saline-sodic condition (Table 4.10) shows that genotype CSR 27 and Nerica 2 maintained all six recorded parameters by having less than 50% reduction over the control, therefore rated highly tolerant. These were followed by Getu which maintained four out of six parameters therefore rated tolerant. The rest of the genotypes maintained less than four parameters therefore rated sensitive to highly sensitive.

Table 4.11 Rice genotypic performance calculated on the basis of less than 50 % reduction in the character measures under saline – sodic condition.

	Characters							
Genotype	Injury	No of tillers	Plant height	Spikelet fertility	No of grains/ panicle	1000-grain wt	No of variables	Rating
CSR 27	+	+	+	+	+	+	6	HT
Getu	-	+	+	-	+	+	4	T
IR 56	-	+	-	-	+	+	3	SS
IR 64	-	-	+	-	-	+	2	S
IR- 67076-2B-21-2	-	-	-	-	-	+	1	HS
Kisegese	-	-	-	-	-	-	0	HS
Nerica 1	-	+	-	-	-	-	1	HS
Nerica 2	+	+	+	+	+	+	6	HT
Pokkali	-	+	-	-	+	+	3	SS
Thailand	-	+	-	-	+	+	2	S
TXD 306	-	+	-	-	-	+	2	S

Note: + = Less than 50 % reduction over control, - = More than 50 % reduction over control
HT = Highly tolerant, T = Tolerant, HS = Highly sensitive ;SS = slightly sensitive; S = Sensitive,

Strong deviations in the rank orders of genotypes were observed. A genotype occupied the top positions in one parameter as an indication of tolerance, occupied the bottom position in a different parameter. This indicated that no grouping of tolerant traits in one genotypes could be achieved, the traits were scattered among genotypes probaly due to the effects of different genes controlling tolerance in these genotypes. This has also been reported by Boyd and Rogers (2004) and Flowers (2004). Manifestation of stress tolerance by plant species at any growth stage is important because it has implications for economic yield. In view of the inter- and intra-specific differences, it is becoming increasingly important to explore this variation and select materials with desirable traits.

4.3 Conclusion

From these experiments it can be concluded that:

1. Genotypes Pokkali, IR67076-2B-21-2 and IR 56 showed outstanding performance in saline condition whereas CSR 27 and Nerica 2 showed good performance under saline sodic conditions. The outstanding performance of these genotypes under specific salt stress environment makes them useful donors for salt tolerance.

2. Among the local farmer preferred varieties, IR 56 had superior performances under both saline and saline-sodic conditions. Based on its ability to grow well, absorbing less Na^+ and maintain high K^+ content under salinity stress, and maintain good tillering ability, number of grains per panicle and 1000 grain weight, IR 56 can be used to breed for tolerance in saline and saline sodic conditions.

3. The experiment also revealed that, except for IR 56 which had moderate performance under saline and saline sodic conditions all the genotypes which performed well under saline condition, had poor performance under saline-sodic conditions. This suggests that genotypes selection should be done under specific salt condition.

4. Plant vigour, less injury symptoms, shoot fresh and /or dry weight, low leaf Na^+ and low Na^+/K^+ concentrations are good indicative characteristics of a better performing genotype at the vegetative stages, whereas, spikelet fertility, grains per panicle and 1000-grain weight are useful at reproduction stage. It can therefore conclude that that, these traits in combination could make good criteria for selection of salt tolerant materials under saline and saline-sodic conditions.

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Chapter Five

Gene action and combining ability of rice genotypes for yield and associated morpho-physiological traits under saline and sodic environments

Abstract

Gene action and combining ability studies for yield and eight morpho-physiological traits of rice genotype were studied under contrasting normal, saline and sodic soils environments. The rice populations were generated through 7 x 7 full diallel crosses. The parents comprised two donors for saline tolerance, one donor for sodic tolerance and four salt sensitive farmers preferred varieties. Both additive and non-additive gene effects are important in the inheritance of characters studied in all soil environments. However, additive effects were more important for number of tillers, shoot Na^+, Na^+/K^+ ratio and plant height and both additive and non-additive gene effects were important for spikelet fertility, days to 50% flowering, number of grains per panicle, 1000-grain weight, and grain yield. Amongst the parental lines, the best general combiners for yield along with other traits were TXD 306 and IR 67076-2B-21-2 under normal non-saline/sodic conditions; IR 56, Pokalli and TXD 306 under saline conditions and CSR 27 and TXD 306 under sodic conditions. Reciprocal effects were observed and both maternal and non-maternal effects were significant with relatively larger maternal than non-maternal effects influencing traits under both control non-saline/sodic conditions and saline conditions. However, only maternal effects were important for characters measured under sodic conditions. The overall results from this study indicated the possibility of improving both yield and salt tolerance from this set of germplasm. However, presence of cytoplasmic gene effects may play a role in modifying the salt tolerance. Therefore, suggesting that tolerant plants should be used as females.

5.0 Introduction

In North eastern Tanzania rice is produced under saline and sodic soil conditions which compromise grain yield. The yield potential of current modern rice varieties in the affected irrigation schemes has stagnated. Reclamation, drainage and water control can minimize the extent and spread but not a permanent solution to the problems (Tesfai *et al.,* 2002). In addition engineering and management costs are high for a resource poor farmer. Therefore deployment of salt tolerant cultivars has been suggested (Mahmood *et al*., 2004). Currently, farmers' preferred rice varieties can be modified and improved for salt tolerance (Manney, 2004) with positive impact on yield.

The National Rice Research Institutes (ARIs) has so far developed a number of modem rice varieties suitable for different ecosystems (Kanyeka *et al.,* 1995). The yield potential of these rice varieties vary due to salt stress conditions in these irrigation schemes (Kips and Ndondi, 1990) located in semiarid and arid environments (Manney, 2004). Developing rice cultivars with improved performance that can withstand salt affected soil is difficult but very important for irrigated areas prone to salt soil problems (Flowers, 2004), However, a viable breeding programme can be developed after an understanding the genetic control of the plant genotypes under salt stress conditions (Mahmood, *et al.,* 2004; Geetha *et al.,* 2006).

Considerable conventional breeding efforts to increase salt tolerance have been made (Mahmood *et al.,* 2004; Manney, 2004; Flowers, 2004; Geetha, *et al.,* 2006) in other environments. However, such studies are limited particularly in sub-Saharan Africa environments. The information on genetic behaviour and mode of inheritance of different morpho-physiological traits under saline and sodic environments are not available in the literature. According to Mahmood *et al*. (2002) salt tolerance is complex and its expression may change with the plant and possibly with existing preconditioning. Based on several studies on sodicity and salinity stress over the years, it has been reported that rice varieties vary in their tolerance to salt levels in the soil. Significant variations in phenology, morphology and physiology across environments have been observed among genotypes (Zeng *et al.,* 2002; Moradi *et al.,* 2003; Davenport *et al.,* 2005; Munns *et al.,* 2006).

Several studies on the genetics of salt tolerance have been carried out. Gregorio and Senadhira (1993) reported the genetics of salinity tolerance in varieties Nona Borka, Pokkali, and SR 26B using the culture solution method and the Na^+/K^+ ratio was used as a criterion for selecting parents with high general and specific combining abilities. Their study revealed that improved lines were good general combiners and reciprocal differences were observed, suggesting that tolerant plants should be used as females. Jones (1986) also studied the genetics of salt tolerance in two mangrove varieties, viz. Pokkali and Pa Merr 108A in Sierra leone. Relative root lengths were the criterion for measuring salt tolerance in saline and non saline conditions. The study indicated additive genetic variation, maternal effects, and transgressive segregation in parents and the progenies. Mahmood *et al.* (2002) reported that shoot length, Na^+ and Ca^{++} content of shoot and the root and shoot dry weights showed significant additive effects with high heritability. Mahmood *et al*. (2004) found that both additive and dominance effects were important for characters such as plant height, panicle length, shoot Na^+ and K^+concentrations.

Likewise Geetha *et al.*(2006) carried out genetic analysis under sodic environments and indicated that both additive and non-additive gene action governed sodicity tolerance. They also identified the best combiners for grain yield and a significant reciprocal variance indicated the influence of maternal inheritance. Marked environmental influences and genotypic effect for salinity and sodicity tolerance has already been established. Many efforts have been made elsewhere to improve cultivated rice varieties for salt-tolerance and studies on the associated genetics. Such studies have never been done in local varieties grown under Tanzanian, and sub Saharan Africa environments at large. Therefore, the present study was undertaken to elucidate genetic mechanism governing various morpho-physiological parameters in rice genotypes under saline and sodic soil conditions in Tanzania.

The specific objectives of this study were to:

(i) investigate the type of gene action governing the morpho-physiological traits under salt saline and sodic environments,

(ii) determine the combining ability of the rice populations under saline and sodic environments,

(iii) determine the role of maternal effects for the inheritance of the morpho-physiological traits measured.

The hypotheses of this study were as follows:

(i) additive gene effects are the predominant form of gene action conditioning tolerance to salt in the tested genotypes,

(ii) rice cultivars are good general combiners for yield,

(iii) maternal effects control the inheritance of morpho–physiological traits under saline and sodic conditions.

5.1 Materials and methods

5.1.1 Germplasm and experimental plan

The hybridization experiment was conducted at soil research institute (ARI) Mlingano, Tanga, Tanzania. Seven parent genotypes were used. The parents involved were four local farmer preferred salt sensitive varieties (TXD 306 – SARRO, IR 64, IR 56, Thailand) three salt tolerance donor parents (Pokkali – highly saline tolerant, CSR 27 – highly sodic tolerant and a moderately salt tolerant IR67076-2B-21-2). These genotype characteristics were explained in chapter 4 (Table 4.2) of this thesis. These seven parents were crossed in a 7x7 full diallel mating scheme. The crossed F1 seed and also the selfed grains from the parents were advanced to F_2 generation. All the F_2 populations along with their parents were evaluated in four (saline, sodic, saline – sodic and control- non saline/sodic) soil environments in two different sites i.e. at Mkomazi and Mombo villages in Korogwe districts, Tanga region. Evaluation of F_2 materials in saline-sodic soil environment was conducted in Mkomazi whereas, for saline, sodic and control-normal soil environments were conducted in Mombo irrigation scheme.

5.1.2 Location and environmental parameters at Mkomazi and Mombo irrigation schemes

Mkomazi irrigation scheme is situated at 04^o39.241' Latitude S and 038^o04.164' longitude E, at an average altitude 452m a.s.l. Mombo irrigation scheme is situated at 04^o39.095' Latitude S and 038^o41.250' longitude E, at an average altitude 400m a.s.l. Both villages used to have reliable bimodal rainfall pattern during the 70s and 80s, but presently unreliable bimodal rainfall pattern is experienced. Long rains start in March through May while the short rains continue from September through December. Periods between the months of January-February and June-August are the dry seasons for the Mombo area. Figure 5.1 shows Mombo evapo-transpirative characteristics and reveals that mean evapo-transpirative deficit being dominant throughout the year and rain days are fewer (Figure 5.2), adding constrains for rice productivity. The scheme is sustained by a water reservoir dam which was described to be unsatisfactory by the users.

5.1.3 Biophysical characteristics of Mkomazi and Mombo experimental sites

The study was carried out from Dec 2009 to August 2010 on natural occurring saline and sodic and saline-sodic soils in two different irrigated sites at Mkomazi and Mombo villages. Mkomazi irrigation site is characterised mainly by local and unimproved irrigation infrastructure and high levels of salt particularly sodic and saline – sodic salts in some fields. Mombo Irrigation Scheme has improved irrigation infrastructure with both saline and sodic salt affected areas (Chapter three). Rice fields of required salinity and sodicity levels were selected. Soil samples were collected from each of the selected experimental field and taken to Mlingano soil Laboratory to measure the soil pH, electrical conductivity (EC) and sodium adsorption ratio (SAR).

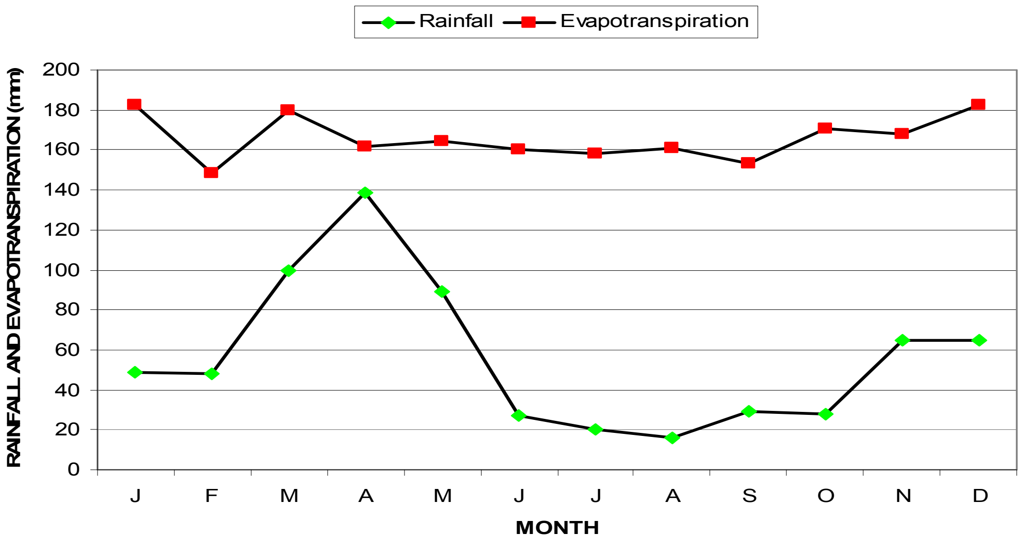


Figure 5.1 Rainfall and evapotranspiration at Mombo

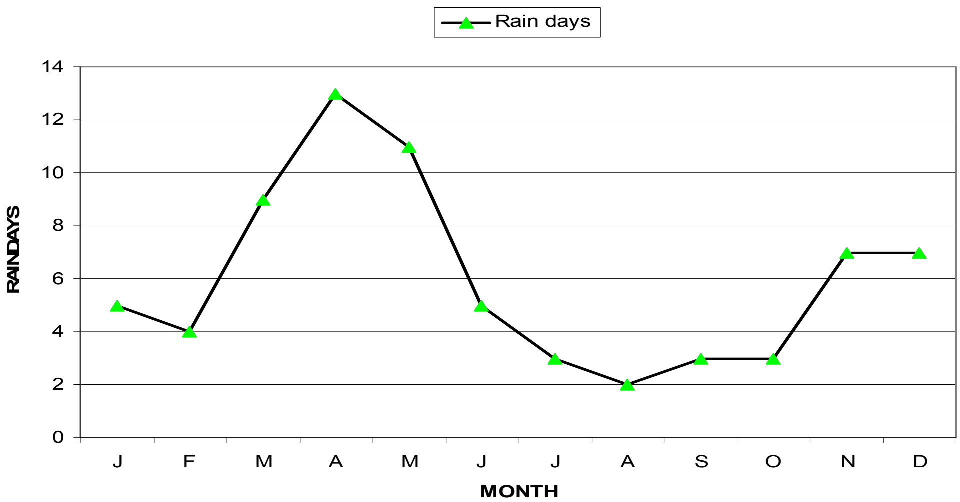
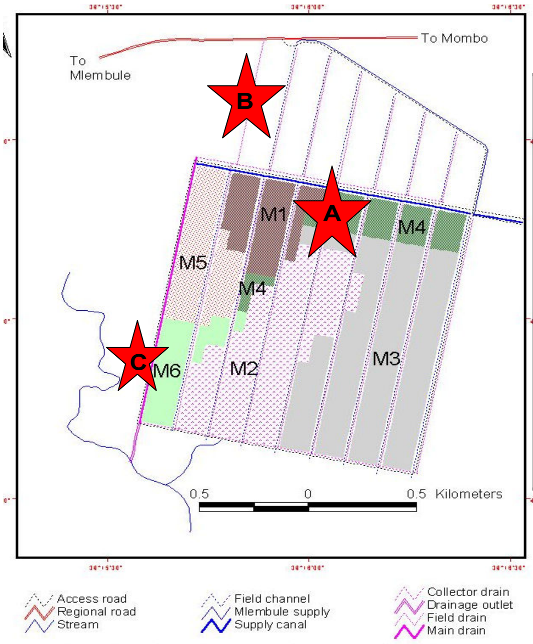


Figure 5.2 Rain days during an average year at Mombo

Two experimental fields (a) with a combination of saline-sodic (Ec = 3.89 dSm^{-1}, pH = 8.8 and SAR = 17.4) and (b) normal soil (Ec = 0.34 dSm^{-1}, pH = 7.2 and 0.26 SAR) were used at Mkomazi Irrigation Scheme, whereas, three different experimental fields with different salt conditions (a) saline (EC 4.24 dSm^{-1}, pH = 7.8, SAR = 4.5), (b) Sodic (EC 1.04 dSm^{-1}, pH = 8.9, SAR = 25.8 and (c) control- non saline/sodic field (Ec = 0.34 dSm^{-1}, pH = 7.7, SAR = 3.6 SAR) were used at Mombo irrigation scheme (Figure 5.3).



Plot No	Area(ha)	Soil pH	EC(1:5)	ESP
M1	16	8.7	0.5 - 2	26 - 35
M2	40	7.7	1 - 3.4	16 - 25
M3	60.5	7.7	0.2-1.5	6 - 15
M4	14.5	7.2	0.7	< 6
M5	18	7.9	>4.5	10 -15
M6	11	7.7	3-6.6	5 - 15
BL P (site B)	9	8.9	0.5-1.7	26 - 35

Figure 5.3 Mombo experimental sites and the associated soil characteristics
(A - control- non saline/sodic; B - Sodic and C – Saline sites)

5.1.4 Experimental design

The F_2 seeds of 49 entries (including 42 progenies and 7 parents) were planted on the 3rd Dec 2009 and 4th March 2010 at Mkomazi and Mombo, respectively. Seeds were planted in seedling trays to ensure recovering of all the geminated seeds and safe transportation to the experimental sites (Figure 5.4). Seedlings were transplanted on the 23rd Dec 2009 and 1st May 2010 at Mkomazi and Mombo experimental plots respectively. Fields were ploughed, flooded, paddled, levelled and transplanted in 1m x 4m plots arranged in 7x7 simple lattice experimental designs with two replicates. Each plot had 4 rows and 80 plants total per replication space planted in 20cm x 20cm apart. After transplanting, few seedlings were reserved for gap filling which was done one week after transplanting. Unfortunately, the whole of Mkomazi (saline-sodic evaluation) experimental plots were completely destroyed by floods which occurred a week after transplanting. Therefore, evaluation proceeded in saline, sodic and the control non-saline/sodic soils at Mombo Irrigation Scheme.

Figure 5.4 Planting of F_2 seeds in trays to ensure proper germination and easy transportation to the experimental sites

5.1.5 Management of experimental plots

The experimental fields were hand weeded continuously; fertiliser as well as insecticides and fungicides were also applied. Fertilizer was applied twice, as a basal application at the rate of 200 kg ha^{-1} of 20-10-10, N-P-K and top-dressed with urea (46% N) at the rate of 100 kg ha^{-1} at four and six weeks after transplanting. Three weeks after transplanting standard insecticides and fungicides was applied fortnightly.

Although the experiment was conducted during the rainy season, it was evident from Figure 5.2 and 5.3 that generally the rainfall was below the average and rain days were very few and very erratic. As a result evapo-transpirative deficits in March-May were still relatively higher than January – February. This resulted in poor water availability and distribution in experimental sites located down stream at the end of the scheme (Figure 5.3). Due to inadequate amount of water available the level of salt stress tends to be high. In five weeks after transplanting the stress in both saline and sodic fields were observed to be high so that most plants were negatively effected especially in the sodicity environment which showed more highly injured and stunted crops than the saline experimental plots. Flush flooding of the experimental fields was done twice within 48 hours in all the plots including the control to minimize the negative effects of saline salt. This was followed by application of $ZnSO_4$ at 10kg ha^{-1} to take care of Zn deficiency which tends to be common especially in alkaline soils.This was done to save the plants so that data could be obtained on them.

5.1.6 Data collection

Data collection started at 6^{th} week after transplanting during the vegetative stage. Plant parameters determined were shoot length, shoot %Na^+ and K^+ concentration and Na^+/K^+ ratio, and number of tillers per plant. Spikelet fertility, number of filled grains per panicle, 1000-seed weight and grain yield were determined at maturity stage of the plant. Records were taken on 35 plants per entry and averaged for traits such as number of tillers per plant, plant height, spikelet fertility and grains per panicle. Spikelet fertility was recorded by observing the number of filled grains and estimated the percentage grains fertility. Data were recorded using a scale (IRRI, 1988) and rated, as 1 = highly fertile (>90%), 3 = fertile (75-89%), 4 = partly sterile (50-74%), 7 = highly sterile (<50% to trace) and 9 = (0% – no filled grains).

For plant tissue analysis to obtain shoot Na^+ and K^+ content of the plant, a composite sample was made from five plant shoots harvested from each entry; two sub samples were made from each sample. The harvested samples were dried in an oven at 65°C for 24h and submitted at Mlingano Laboratory for Na^+ and K^+ content determination and Na^+/K^+ ratio was calculated. Five sub samples of well developed 100 grains were weighed on a precision balance at 14% moisture content and converted to 1000 grain weight. Due to high stress level described earlier plants under the sodic environment did not survive up to maturity therefore, only data for the vegetative stage were collected.

5.1.7 Statistical Analysis

The data obtained for different traits were subsequently reduced to progeny means and subjected to ordinary analysis of variance in GENSTAT release 11 (Payne *et al.,* 2008) computer package. The magnitude of additive, dominance and environmental variance from segregating materials were estimated following Singh and Chaudhary (1985). Information on the general and specific combining ability effects of parent and their crosses, respectively, and the nature of genetic parameters were determined in SAS version 9.2 computer program (Zhang *et al.,* 2005) using Griffing's (1956) Method I, model I. Griffing's model was fitted for the GCA and SCA analysis as follows:

$Y_{ijk} = \mu + g_i + g_j + s_{ij} + r_{ij} + e + ge_i + ge_j + s_{ij}e + r_{ji}e + e_{ijk}$; where:

Yijk= observed value of the cross between parent i and j and replication k;

μ= the overall mean;

g_i= the GCA of the parent i;

g_j= the GCA of the parent j;

s_{ij}= SCA of the cross between parents i and j;

r_{ij} = reciprocal effect;

e = environment main effects;

ge_i, gej, $s_{ij}e$, $r_{ji}e$ = Interaction effects of GCA, SCA and reciprocal effects respectively with environment;

e_{ijk} = experimental error.

The relative importance of GCA and SCA was estimated according to Baker (1978) as the ratio *2 ms GCA / (2 ms GCA+ ms SCA*); where *ms GCA* and *ms SCA* are the mean square components for GCA and SCA, respectively.

5.2 Results and discussion

5.2 1 General analysis of measured traits

The analysis of variance (ANOVA) across the environment indicated highly significant differences for mean squares ($P<0.001$) on the tested environments and tested genotype entries for all the traits (Table 5.1 - 5.5). Across environments, except for number of tillers, the interaction between genotype and environment was not significant for all the measured parameters (Table 5.1). The ANOVA within environments (except for number of days to 50% flowering and Na^+/K^+ ratio which were non-significant under control), indicated highly significant genotypic differences. The results confirm the presence of genetic diversity and high variability in the materials used, thus, there is possibility of selection for salt tolerance among the germplasm included.

Similarly, various studies have reported significant differences among genotypes for various rice characteristics like number of effective tillers per hill, plant height, days to 50% flowering, panicle length, grains per panicle, sterility percentage and grain yield per hill under normal- non salt soil condition (Chakraborty *et al*., 2009, Kumar *et al*., 2007; Singh *et al*., 2007), under saline soil conditions (Mahamood *et al.,* 2004) and under sodic conditions (Geetha *et al.,* 2006). The analysis of variance across environments also revealed non-significant interactions between entries and environment for all traits measured except the number of tillers per plant (Table 5.1).

5.2.2 Gene action

Mean squares due to both general combining ability (*gca*) and specific combining ability (*sca*) were significant for all the characters across environments indicating that both additive and non-additive gene effects were important for the expression of characters evaluated for salt tolerance in the rice genotypes used for the study. However, most of the total variability for each character was associated with additive effects as shown by the greater magnitude of GCA means squares. Similar findings have also been reported under saline (Mahmood *et al*., 2004) and under sodic conditions by Geetha *et al.* (2006). The significant GCA x environment mean square effects obtained for all the traits except spikelet fertility, grains per panicle and 1000 grain weight (Table 5.1) suggested that the additive effects were not stable over environments. This has also been reported previously by Saidaiah *et al*. (2010) and Sadeghi *et al*. (2009). It therefore, suggests further that, it is possible to select parental lines to obtain hybrids for specific environments.

This study found within environments that, though the genetic component of variation at both vegetative and maturity stage of plant growth indicated the presence of both additive and non-additive effects to be important in the inheritance of characters studied, additive effects tended to be more important at vegetative stage. Most traits measured during the vegetative stage indicated non-significant SCA but significant GCA mean squares, showing a higher magnitude of additive effects for these traits under the respective environments (Table 5.2, 5.3 and 5.4).

Table 5.1 Mean squares for yield and morpho-physiological traits of rice genotypes across saline, sodic and control environments

Source of variation	d.f	No of tillers	%Na	Na^+/K^+	Plant height	Spikelet fertility [a]	Days to 50% flowering[a]	Grains/panicle[a]	1000 Grain wt [a]	Yield tha^{-1} [a]
Environments	1/2[a]	2959.6***	34.7***	16.8***	2872.3***	388.7***	291.4***	60098.6***	521.4***	45.2***
Replication	3	7.2**	0.17*	0.17*	44.2*	0.08ns	5.4ns	28.91ns	17.9*	1.7**
Genotypes	48	17.0***	1.21***	0.70***	159.8***	7.4***	34.0***	736.4***	99.8***	1.4***
Envir*Geno	48	14.1**	0.24ns	0.08ns	9.5ns	2.02ns	5.5ns	179.6ns	7.3ns	0.2ns
Pooled Error	96	8.5	0.27	0.05	10.7	1.7	5.0	173.3	6.9	0.3
GCA	6	61.68***	4.55***	0.67***	2968.32***	21.80***	77.49***	1434.7***	77.13***	5.77***
SCA	21	15.76*	0.75***	0.21*	249.29**	8.30***	32.86***	695.14***	17.55***	1.13***
Reciprocal	21	5.42ns	0.81***	0.11*	270.21***	2.45ns	22.65***	576.31***	5.71ns	0.30ns
Maternal	6	2.01ns	0.59***	0.22**	465.93***	2.23ns	26.452***	641.64**	4.84ns	0.34ns
Non-maternal	15	6.78ns	1.08***	0.07ns	191*	2.53ns	21.13***	554.37**	6.01ns	0.29ns
GCA*Envir	12	45.37***	1.08***	0.32***	298.84**	1.65ns	13.33*	224.6ns	2.00ns	0.81*
SCA*Envir	42	13.88*	0.11ns	0.03ns	89.78ns	2.66*	4.43ns	1.20ns	8.41ns	0.24ns
Rec*Envir		5.38ns	0.12ns	0.05ns	42.80ns	1.50ns	2.27ns	137.7ns	7.73ns	0.41ns
GCA/SCA[#]		0.89	0.92	0.86	0.95	0.84	0.82	0.80	0.90	0.91
CV		*22.2*	*30.1*	*31.1*	*14.6*	*26*	*2.0*	*11.2*	*10.6*	*24.2*
R^2		*0.87*	*0.81*	*0.85*	*0.87*	*0.85*	*0.82*	*0.86*	*0.75*	*0.80*

***, **. *, ns = Highly significant at P=0.001, P=0.01, P=0.05 and ns = non - significant respectively

[a] The genotypes mean squares representing two environments (Normal soil-Control and Saline environments)

[#]Ratio = {2GCA/2GCA+SCA} (Bakers, 1978)

For example, except for plant height and number of tillers per plant which showed significant SCA mean squares under normal - non salt soil and sodic environments, respectively, all the traits *viz* number of tillers, shoot Na^+, Na^+/K^+ ratio and plant height had non significant SCA mean squares in all the three environments. Therefore these characters are mainly governed by additive gene action. The traits might be useful selection criteria for salt tolerance at the vegetative stage as additive gene effect can be easily fixed in self pollinated crops. Similar observation has also been reported by Moeljopawiro *et al.* (1981) that shoot length, Na^+ and Ca^{++} content of shoot and the root and shoot dry weights showed significant additive effects with high heritability.

On the contrary, Mohamed *et al*. (2004) found that both additive and dominance effects were important for characters such as plant height, panicle length, shoot Na^+ and K^+ concentration and observed the preponderance of additive gene action for the traits. According to Mohamed *et al.* (2004) predominance of additive gene effects offers a high degree of reliability during selection and allows reliable selection in early segregating generations. However, a significant environmental variance examined in this study for the characters including Na^+, Na^+/K^+ (Table 5.1) need to be put into consideration when the traits have to be used as criteria for selection, for example the use of pot experiments or controlled environment can help to minimize soil environmental variability and improve selection using these traits.

All the traits measured at maturity stage of the plant *viz* spikelet fertility, days to 50% flowering, number of grains per panicle, 1000 grain weight, and grain yield had significant mean squares for both GCA and SCA effects under all the tested environments indicating that both additive and dominance gene effects were important for the expression of these characters. However, the data showed preponderance of additive gene action. Similar observation has been reported in rice (Pradhan *et al.,* 2006; Mahmood *et al.,* 2004).

Table 5.2 Mean squares for various traits of rice genotypes grown under control no-saline/sodic soil condition

Source of variation	d.f	Number of tillers	%Na	Na/K	Plant height	Spikelet fertility	Days to 50% flowering	Grains per panicle	1000 Grain wt	Yield tha^{-1}
Replication	1	5.93ns	2.06*	0.04*	1.25ns	0.71ns	1.02ns	56.48ns	2.51ns	3.01*
Genotypes	48	10.0***	0.56*	0.14**	278.6***	3.36**	24.08ns	455.42***	12.02***	1.10***
GCA	6	22.21**	1.62***	0.09***	1420.09***	9.32***	66.56***	468.34*	34.29***	4.63***
SCA	21	9.80ns	0.37ns	0.02ns	100.77***	3.89***	18.80***	510.22***	9.20*	0.74**
Reciprocal	21	6.76ns	0.43ns	0.03ns	118.63***	1.14ns	17.22**	325.67*	8.47*	0.46ns
Maternal	6	3.75ns	0.50ns	0.04ns	218.50***	1.38ns	20.04**	255.34ns	6.64ns	0.76ns
Non-maternal	15	7.96ns	0.40ns	0.03ns	78.68**	1.04ns	16.09**	353.77*	9.21*	0.34ns
Error	48	6.19	0.32	0.02	32.41	1.58	6.22	160.0	4.70	0.35
CV		*16.0*	*31.1*	*29.2*	*6.73*	*29.1*	*2.61*	*10.0*	*8.12*	*24.0*
R^2		*0.71*	*0.66*	*0.65*	*0.89*	*0.68*	*0.80*	*0.74*	*0.72*	*0.76*
GCA/SCA#		0.82	0.88	0.90	0.93	0.82	0.88	0.64	0.88	0.93

***, **. *, ns = Highly significant at P=0.001, P=0.01, P=0.05 and ns = non - significant respectively
#Ratio = {2GCCA/2GCA+SCA} (Kang's 1994; Bakers, 1978)

Table 5.3 Mean squares for various traits of rice genotypes grown under saline soil condition

Source of variation	d.f	Number of tillers	%Na	Na/K	Plant height	Spikelet fertility	Days to 50% flowering	Grains per panicle	1000-Grain wt	Yield tha^{-1}
Replication	1	4.40ns	0.02*	0.21*	30.7ns	0.16ns	9.8ns	0.38ns	73.4*	0.37ns
Genotypes	48	21.8**	28.6***	1.71ns	163.4***	6.09***	15.42***	492.8***	14.11***	0.63***
GCA	6	11.50***	3.05***	0.80***	489.9***	14.12***	24.27***	1191.03***	44.85***	1.94***
SCA	21	1.51ns	0.25ns	0.09ns	101.27ns	7.09***	18.49***	394.22*	16.77*	0.64*
Reciprocal	21	*4.86ns*	*0.24**	*0.08ns*	*132.50**	*2.80**	*9.82***	390.70**	*4.96ns*	*0.25ns*
Maternal	6	2.64ns	0.67**	0.10ns	253.61**	2.23ns	8.67*	474.43*	4.12ns	0.26ns
Non-maternal	15	5.74ns	0.07ns	0.07ns	84.05*	3.03*	10.27**	357.21*	5.29ns	0.24ns
Error	48	9.90	0.17	0.11	82.3	1.75	3.92	186.1	9.21	0.30
CV		*18.8*	*19.5*	*27.4*	*11.8*	*24.1*	*1.75*	*13.4*	*13.0*	*28.3*
R^2		*0.69*	*0.78*	*0.67*	*0.67*	*0.78*	*0.80*	*0.72*	*0.67*	*0.78*
GCA/SCA#		0.94	0.96	0.94	0.91	0.80	0.72	0.86	0.84	0.86

***, **. *, ns = Highly significant at P=0.001, P=0.01, P=0.05 and ns = non - significant respectively
#Ratio = {2GCCA/2GCA+SCA} (Bakers, 1978)

Table 5.4 Mean squares for various traits for rice genotypes grown under sodic soil condition

Source of variation	d.f	No of tillers	%Na	Na/K	Plant height
Replication	1	9.71ns	2.10*	0.12*	42.7*
Genotypes	48	15.44*	0.61**	0.23**	354.1*
GCA	6	26.61*	1.99***	0.42***	165.09***
SCA	21	18.42*	0.37ns	0.08ns	22.04ns
Reciprocal	21	4.57ns	0.45*	0.10*	104.81ns
Maternal	6	4.29ns	0.59*	0.15*	78.09ns
Non-maternal	15	4.68ns	0.39ns	0.08ns	115.50ns
Error	48	9.32	0.32	0.06	106.0
CV		*29.1*	*29.2*	*30.1*	*27.8*
R^2		*0.65*	*0.67*	*0.69*	*0.68*
GCA/SCA		1.45	1.62	5.25	15.35
GCA/SCA[#]		0.74	0.91	0.89	0.94

***, **. *, ns = Highly significant at P=0.001, P=0.01, P=0.05 and ns = non – significant, respectively
[#]Ratio = {2GCCA/2GCA+SCA} (Kang's 1994; Bakers, 1978)

The results from the current study are also in line with those reported by Narayanan and Rangasamy (1991) that additive and dominance gene effects were important for days to 50% flowering, number of grains per panicles and 1000 grain weight under both saline and non-saline environments. Their results also found both additive and non-additive effects were important for number of tillers and plant height under both saline and non saline environments which is contrary to the findings of the current study. The current study found plant tillers to be controlled by additive gene action under both saline and control non-salt stress environment which was also reported by Mahmood *et al.* (2004), and both additive and non additive gene effects found to be important for plant tillers under only sodic environment. Thus suggested that selection using this trait can be done in early stages of plant growth under normal and saline conditions, but selection under sodic environment should be delayed to later generations.

Results indicated further on the contribution of non-additive gene effects for the measured traits that, although the total variability for each character was associated with mainly additive gene effects as shown by the greater magnitude of GCA mean squares, it was also depicted that GCA mean squares were several times greater than SCA mean squares for all the traits within individual environments. The GCA/SCA ratio being very close to unity (0.82 to 0.93) for all the traits except for number of grains per panicle which indicated lower GCA/SCA ration (0.64). This indicated that additive gene effects were more prominent at vegetative stage and that non-additive gene effects were also important for some of the traits measured at maturity stage especially for number of grains per panicles (Table 5.2). The study observed that GCA/SCA ratio of 0.64 for number of grains per panicle under normal soil was revised under saline environment (0.86) indicating the preponderance of additive gene action for the trait under saline condition (Table 5.3).

The traits governed by additive gene action are usually required in a breeding programme as additively controlled traits offer a higher degree of reliability during selection and allow reliable selection in early segregating generations. As shown in this experiment all the traits *viz* number of tillers, shoot Na^+, Na^+/K^+ ratio and plant height could be manipulated in a breeding programme. The significant GCA mean squares for all the traits indicated variability of GCA among the parents and this suggests that genetic gain is achievable through selection over the segregating populations. Similar observations have been reported in rice (Pradhan *et al.,* 2006; Mahmood *et al.,* 2004) and other different crop species (Arunga *et al.,* 2010; Sadeghi *et al*., 2009). Conflicting results found in the studies might be due to differences on the testing environments and the genotypes used.

5.2.3 Combining ability effects

General combining ability effects under non-saline/sodic soil environment

Under control- normal soil condition, only parent IR 56 showed to be a good general combiner for number of tillers per plant and had significantly positive GCA effect. For both shoot Na^+ concentration and Na^+/K^+ ratio, parents IR 67076-2B-21-2 and CSR 27 significantly exhibited negative GCA effects (Table 5.5). As regard to plant height, IR 67076-2B-21-2 and IR 64 were good general combiners, and for the case of days to 50% flowering, two parents Pokkali and Thailand showed to be good general combiners for the trait. Three parents IR 67076-2B-21-2, TXD 306 and IR 64 showed to be good general combiners for spikelet fertility (Table 5.6). Parent TXD 306 was a good general combiner for number of grains per panicle and parents TXD 306 and IR 56 were good combiners for 1000-grain weight. Yield being an ultimate product of all traits is very important. Three parents: TXD 306, IR 67076-2B-21-2 and IR 64 showed desirable positive GCA effects for yield indicating to be good general combiners for this trait and contributed positively towards yield increase in crosses (Table 5.7). Pokkali displayed a highly significant but negative GCA effect for yield indicating that the line, in general, contributed towards low yield in crosses under normal soil conditions.

General combining ability effects under saline soil environment

Under saline soil condition, parents IR 56 and IR 64 were good general combiners for the number of tillers per plant. For shoot Na^+ concentration, three different parents were recorded. These are Pokkali, Thailand and IR 56 which showed negative GCA effects for shoot Na^+ concentration, and only parent Pokalli showed a significant negative GCA effect for Na^+/K^+ ratio (Table 5.5). Sodium is a major toxic element under saline and sodic environment (Acquaah, 2007) therefore, a negative GCA effects for these lines indicate their contribution to minimum Na^+ concentration in plant tissue therefore exhibit the possibility of their crosses to exclude and absorb less Na^+ under these environments, which is a characteristic needed for a salt tolerant plant. Parents TXD 306 and CSR 27 had significantly positive GCA effect for Na^+ and Na^+/K^+ ratio, indicating their contribution toward Na^+ susceptibility which negatively affects plant growth under both saline and sodic conditions (Acquaah, 2007).

Two parents IR 67076-2B-21-2 and IR64 showed to be good general combiners for plant height. Parents Pokkali and IR 56 were good general combiners for days to 50% flowering and spikelet fertility, respectively (Table 5.6). Three parents TXD 306, CSR 27 and IR56 showed to be good general combiners for number of grains per panicle by exhibiting significantly higher and positive GCA effects. For 1000 grain weight, parents TXD 306 and IR 56 exhibited significantly positive GCA effects and therefore good general combiners for the trait. Two parents IR 64 and IR 56 showed desirable significant positive GCA effects for grain yield under saline condition (Table 5.7) indicating positive contribution toward yield in crosses.

General combining ability effects under sodic soil environment

Only parent TXD 306 showed a highly significant but negative GCA effect for the number of tillers, indicating that this parent contribute to high tillering reduction under sodic condition in most of crosses. Regarding the shoot Na^+ concentration, two parents IR 67076-2B-21-2 and CSR 27 were good general combiners by having a negative GCA effects indicating also their contribution to minimum Na^+ concentration in plant tissue in their crosses. Parent TXD 306 and IR 64 exhibited significantly higher and positive GCA effect for Na^+ and Na^+/K^+ under this environment, indicating that these parents were highly susceptible and contributed to high Na^+ absorption in most of crosses. For shoot Na^+/K^+ ratio, only CSR 27 had significantly negative GCA effect therefore showed to be a good general combiner for the trait, indicating that CSR 27 conreibited to less Na^+

Table 5.5 Estimates of general combining ability (GCA) effects for number of tillers, shoot Na concentration and Na/K ratio in individual environments

Parents	No of tillers			Shoot Na content			Shoot Na/K		
	Control	Saline	Sodic	Control	Saline	Sodic	Control	Saline	Sodic
Pokkali	-1.307**	-4.100***	0.786ns	-0.139ns	-0.550***	-0.539ns	-0.030ns	-0.329***	-0.011ns
IR67076-2B-21-2	0.443ns	-0.283ns	0.371ns	-0.211*	-0.027ns	-0.191*	-0.046*	0.025ns	-0.061ns
CSR 27	0.226ns	0.183ns	0.921ns	-0.200*	0.329***	-0.343***	-0.043*	0.175**	-0.161***
TXD 306	-0.267ns	0.704ns	-1.758**	0.447***	0.446***	0.467***	0.101***	0.162*	0.217***
IR 64	1.039ns	1.438**	0.696ns	0.173ns	0.049ns	0.194ns	0.047*	0.046ns	0.101*
Thailand	-0.977*	0.486ns	-0.472ns	0.045ns	-0.191**	0.339ns	0.014ns	-0.066ns	-0.036ns
IR 56	0.842*	1.572**	-0.543ns	-0.109ns	-0.056ns	-0.112ns	-0.039ns	-0.014ns	-0.048ns
Std (gi)±	0.44	0.55	0.53	0.09	0.07	0.09	0.02	0.05	0.04
Std (gi-gj)±	0.67	0.84	0.81	0.14	0.11	0.15	0.03	0.08	0.06

***, **. *, ns = Highly significant at P=0.001, P=0.01, P=0.05 and ns = non – significant, respectively

Table 5.6 Estimates of general combining ability (GCA) effects for plant height, days to 50% flowering and spikelet fertility under individual environments

Parents	Plant height			Days to 50% flowering		Spikelet fertility	
	Control	Saline	Sodic	Control	Saline	Control	Saline
Pokkali	13.198***	5.859***	14.802***	-2.556***	-1.617***	1.112***	1.581***
IR67076-2B-21-2	-3.583***	-2.885*	-3.416ns	1.944***	1.061**	-0.388*	-0.275ns
CSR 27	-0.683ns	-0.316ns	1.314ns	0.836*	-0.403ns	0.326ns	0.010ns
TXD 306	03.388**	-0.801ns	-10.576***	1.372**	0.990**	-0.531**	-0.276ns
IR 64	-9.771***	-6.921***	-3.127ns	-0.770ns	0.346ns	-0.459*	0.281ns
Thailand	1.377ns	3.188*	0.452ns	-0.878*	0.061ns	-0.102ns	-0.346ns
IR 56	2.850**	1.877ns	0.550ns	0.051ns	-0.439ns	0.040ns	-0.418*
Std (gi)±	0.99	1.59	2.51	0.43	0.34	0.22	0.23
Std (gi-gj)±	1.52	2.42	3.84	0.67	0.52	0.33	0.35

***, **. *, ns = Highly significant at P=0.001, P=0.01, P=0.05 and ns = non – significant, respectively

Table 5.7 Estimates of general combining ability (GCA) effects for grains per panicle, 1000-grain weight and yield in individual environments.

Parents	Grains per panicle		1000 Grain wt		Yield tha^{-1}	
	Control	Saline	Control	Saline	Control	Saline
Pokkali	-5.701**	-4.592*	-0.184ns	-0.332ns	-0.738***	-0.553***
IR67076-2B-21-2	-2.600ns	-0.501ns	-0.927**	-1.497**	0.280**	0.106ns
CSR 27	1.385ns	5.643*	-1.659***	-1.439**	-0.014ns	-0.109ns
TXD 306	6.371**	7.950***	1.719***	1.742***	0.480***	0.076ns
IR 64	-0.950ns	-7.308**	-0.045ns	-0.393ns	0.298**	0.203*
Thailand	-2.121ns	-7.730**	0.280ns	0.685ns	-0.169ns	0.109ns
IR 56	3.161ns	5.911*	0.815*	1.235*	-0.006ns	0.167*
Std (gi)±	2.21	2.38	0.37	0.53	0.10	0.09
Std (gi-gj)±	3.38	3.64	0.58	0.81	0.16	0.15

***, **, *, ns = Highly significant at P=0.001, Significant at P=0.01, Significant at P=0.05 and non - significant, respectively reduction to most of crosses (Table 5.5). Parent TXD 306 displayed significantly negative GCA effect for plant height therefore showed to be a good general combiner for the trait, indicating the contribution of this patent towards dwarfing characteristic under this environment (Table 5.6).

Potential parents for component characters

Performance of parents for more than one trait was observed and rated to identify the potential outstanding general combiners. The results showed parent that IR 67076-2B-21-2 was the best general combiner under normal non-saline/sodic soil condition. The parent also showed to be a good general combiner for the traits measured under both vegetative and reproductive stages of plant growth, therefore rated as a high general combiner; this was followed by TXD 306, IR 64 which also showed good general combining ability in more than one trait and in more than one environment, therefore, rated as a high general combiners. Parents CSR 27 and IR 56 were rated as average combiners and finally Pokalli and Thailand as low general combiners. The best general combiner was observed in Parent IR 56 for the traits in both vegetative and maturity stage under saline environment and therefore rated as high general combiner, followed by parents Pokkali, IR 64 and TXD 306 which rated as average general combiners, and parents IR 67076-2B-21-2, CSR 27 and Thailand rated as low general combiners. Results showed further that parent CSR 27 showed to be a good general combiner for sodic soil environment therefore rated high and only parents IR 67076-2B-21-2 and TXD 306 showed average general combining. The rest of parents showed poor general combining ability under this soil environment.

From this study it can be suggested that in order to synthesize a dynamic population with most of the favourable genes accumulated, it will be pertinent to make use of these parents IR 67076-2B-21-2, IR 56 and TXD 306 which showed high and desirable general combining ability for several characters in all the environments in multiple crossing programme. Therefore could be utilized extensively in the hybridization programme to accelerate the pace of genetic improvement of grain yield in rice under salt environments.

The GCA variance is primarily due to the function of the additive genetic variance and represents a fixable portion of genetic variation. If epitasis is present, GCA also includes additive × additive type of non-allelic interaction (Singh and Narayanan, 2004). Therefore, desirable general combiners isolated in present studies for the traits are recommended to be used in multiple crossing programmes to identify superior genotypes for development of high yielding cultivars for the respective environments.

5.2.4 Specific combining ability effects

The estimates of specific combining ability of potential crosses for nine characters under all the three salt environments (normal, saline and sodic) are presented from Table 5.8 to 5.10. This could be useful in exploitation of heterosis in a hybrid programme. However, in self pollinated crops, additive effects and additive x additive epitasis (if present) can be exploited in developing promising pure lines because these components are fixable. Thus, selection of parents on the basis of GCA effects may be promising in the breeding programme. Analysis of SCA effects of crosses in relation to GCA effects of their parents revealed that expression of SCA effects was independent of the GCA effects of the two parents. All types of SCA effects either from high, low or average of the parents for the traits studied (high × high, high × low, high × average, low × high, low × low, low × average, average × high, average × low and average × average) were observed from any kind of GCA combination of parents for various traits studied. The results therefore indicated that more useful segregants and saline/sodic tolerant homozygous lines can be developed from high and/or low general combiners.

5.2.5 Reciprocal effects

Within environments, variations in reciprocal effects were observed and reported in Tables 5.11 to 5.13. Under normal – non salt soil conditions, highly significant reciprocal effects were observed for plant height, days to 50% flowering, number of grains per panicle and 1000 grain weight. Both maternal and non-maternal effect showed to be significant with relatively larger maternal than non-maternal effects for plant height and days to 50% flowering; and only non-maternal effects were significant for the number of

Table 5.8 Estimates of specific combining ability of crosses for rice traits under normal – control non-saline/sodic soil condition.

Crosses	Characters								
	No of tillers	%Na	Na/K	Plant height	Spikelet fertility [a]	Days to 50% flowering[a]	Grains/panicle	1000 Grain wt [a]	Yield T/ha [a]
Pokkali x IR67076-2B-21-2	-0.190	0.045	0.067	7.965***	0.602	-3.408**	-13.250*	0.208	0.360
Pokkali x CSR 27	-0.034	-0.560*	-0.161**	9.550***	0.887	-1.551	9.214*	-0.004	-0.254
Pokkali x IR 64	1.515	0.060	-0.004	-6.429**	0.173	0.306	-0.750	-2.271*	-0.535*
Pokkali x Thailand	1.358	-0.367*	-0.061	-10.633***	0.316	1.163	-8.128	-1.661	-0.105
Pokalli x IR 56	1.063	0.523	0.116	8.715*	0.571	0.142	-13.528	3.131*	-1.149*
IR67076-2B-21-2 x CSR 27	0.585	-0.377*	-0.107	-2.645	0.387	-0.801	17.457**	-0.225	0.520*
IR67076-2B-21-2 x TXD 306	1.666	0.099	0.018	0.485	-0.255	-0.086	-12.478*	0.545	-0.023
IR67076-2B-21-2 x IR 64	-1.762	0.257	0.056	2.425	0.173	-2.693**	2.042	-0.281	-0.346
IR67076-2B-21-2 x Thailand	-1.703	-0.125	-0.037	1.248	-1.183*	2.913**	-0.985	0.217	-0.058
IR67076-2B-21-2 x IR 56	-0.763	0.345	0.100	-5.410	-1.928*	2.892	-9.871	3.382*	0.971*
CSR 27 x TXD 306	0.025	0.100	0.0169	-7.340**	1.030*	0.270	22.114***	-1.818*	-0.053
CSR 27 x IR 64	-3.338**	0.129	0.055	0.292	-1.040*	0.163	1.157	1.869	0.230
TXD 306 x Thailand	1.421	0.061	0.017	-0.228	-1.040*	0.234	9.448*	-1.655	0.208
TXD 306 x IR 56	-1.491	0.471	0.085	-1.839	0.928	-2.428	27.750**	-1.596	-1.058*
IR 64 x Thailand	1.421	0.0098	0.003	2.101	0.887	-1.372	12.014*	1.234	0.050
IR 64 x IR 56	-1.825	0.0078	-0.017	-7.774*	-2.000*	-2.821	12.478*	1.089	1.479**
Thailand x IR 56	-2.127*	-0.234	-0.073	-4.965	-1.642*	2.071	-8.492	-0.535	0.961*

***, **, * = Highly significant at P=0.001, Significant at P=0.01, Significant at P=0.05 respectively

Table 5.9 Estimates of specific combining ability of crosses for rice traits under saline soil condition.

Crosses	Characters								
	No of tillers	%Na	Na/K	Plant height	Spikelet fertility [a]	Days to 50% flowering[a]	Grains/panicle	1000 Grain wt [a]	Yield T/ha [a]
Pokkali x IR67076-2B-21-2	-3.2062**	-0.044	-0.217*	0.917	1.204*	-2.275**	-9.391	0.861	-0.315
Pokkali x Thailand	-0.265	-0.102*	-0.202*	-5.801	-0.724	0.224	-12.884*	-3.395**	-0.211
IR67076-2B-21-2 x Thailand	-0.192	0.273	0.240*	-1.929	-1.867**	3.045***	1.216	1.568	0.018
IR67076-2B-21-2 x IR 56	-1.036	-1.071*	-0.751*	-0.320	0.642	-1.250	-0.253	1.792	0.426*
CSR 27 x TXD 306	-1.103	0.032	0.085	-10.301*	-0.724	-0.418	-11.129*	-1.821	-0.018
CSR 27 x IR 64	-0.644	0.048	0.020	-2.253	-0.702	-0.775	13.081*	3.114*	0.398
TXD 306 x IR 64	1.667	-0.033	-0.020	-5.153	-1.938**	-0.668	-12.482*	-1.867	0.301
TXD 306 x Thailand	-0.410	0.227	-0.164	1.016	-1.867**	-0.132	8.521	-0.845	0.119
TXD 306 x IR 56	1.154	0.583*	0.147	-15.478*	-1.857*	-4.821***	12.388*	2.281*	-0.598
IR 64 x Thailand	-1.199	0.019	0.513*	5.379	0.632	-2.489**	3.226	1.714	0.172
IR 64 x IR 56	6.483*	0.068	0.033	-0.335	-2.857***	-2.464	-7.567	3.396*	0.815*
Thailand x IR 56	5.106*	-0.082	0.039	-1.125	-2.428***	2.750*	-14.537	0.640	0.307

***, **, * = Highly significant at P=0.001, Significant at P=0.01, Significant at P=0.05 respectively

Table 5.10 Estimates of specific combining ability of crosses for rice traits under Sodic soil condition.

Crosses	Characters			
	No of tillers	%Na	Na/K	Plant height
Pokkali x IR67076-2B-21-2	1.089	-0.039	-0.045	10.204
Pokkali x CSR 27	2.398	-0.482*	-0.255*	12.708
IR67076-2B-21-2 x IR 64	-2.934*	0.236	0.111	-0.360
CSR 27 x TXD 306	0.180	0.243	0.170	-9.146
CSR 27 x IR 64	-2.284	0.272	0.109	-0.360
CSR 27 x Thailand	-0.814*	-0.732*	-0.252*	8.532
CSR 27 x IR 56	0.301	0.426	0.238	1.947
TXD 306 x IR 64	1.360	0.038	0.065	0.321
TXD 306 x Thailand	0.546	0.063	-0.076	1.154
TXD 306 x IR 56	-4.335	-0.495	0.207*	-20.103*
IR 64 x Thailand	-1.448	0.021	-0.081	4.828
IR 64 x IR 56	1.117	0.097	0.054	0.438
Thailand x IR 56	2.668	-0.234	-0.063	-6.082

***, **, * = Highly significant at P=0.001, Significant at P=0.01, Significant at P=0.05 respectively

grains per panicle and 1000 grain weight. These results are in line with findings by Muhammad *et al.* (2010) that maternal effects were significant in 1000 grain weight and fertility percentage in rice.

The current study found non-significant reciprocal effects for number of tillers per plant, shoot Na^+ concentration, Na^+/K^+ ratio and grain yield (Table 5.3). These results are on in contrast, to Muhammad *et al.* (2010) findings that there are maternal effects for number of tillers per plant. Under saline soil conditions, significant reciprocal effects were observed for all characters except number of tillers per plant, shoot Na^+/K^+, and 1000 grains weight and grain yield. Again both maternal and non-maternal effects were significant for plant height, days to 50% flowering and number of grains per panicle. Only maternal and non-maternal effects were significant for shoot Na^+ concentration and spikelet fertility, respectively. Significant reciprocal and maternal effects were only observed for shoot Na^+/K^+ ratio, under sodic soil environment.

Reciprocal differences were attributable to both maternal and non-maternal effects, suggesting that cytoplasmic genes and their interaction with nuclear genes played a significant role in the inheritance of the respective trait in respective environment. According to Evans and Kemicle (2001), maternal effects are attributable to cytoplasmic genetic factors, while non-maternal effects are explained by interaction effect between nuclear genes and cytoplasmic gene effects (Mweshi *et al*., 2010). Significant reciprocal effects have some implications on estimation of genetic effects. It has been found that presence of reciprocal effects especially the maternal type tends to inflate the effect of additive gene effects while the non – maternal reciprocal effects might inflate the non-additive variance (Thach Can *et al.,* 2002; Geetha *et al*., 2006). Therefore, there is a need to consider both nuclear and non-nuclear genetic effects in developing a breeding strategy as these effects might lead to wrong impression of levels of the genetic effects. This suggests further that the need exists for proper choices of male and female parents in hybridization programmes to improve the trait under selection.

Table 5.11 Estimates of reciprocal effects for rice traits under control non-saline/sodic soil condition

Reciprocals	Characters								
	No of tillers	%Na	Na/K	Plant height	Spikelet fertility	Days to 50% flowering	Grains/panicle	1000 Grain wt	Yield T/ha
IR67076-2B-21-2 x CSR 27	0.390	0.099	0.027	-9.265**	0.431	4.021**	4.540	0.076	-0.955
IR67076-2B-21-2 x TXD 306	-0.772	0.302	0.075	-3.050	0.501	2.750*	21.051**	-0.154	-0.492
IR67076-2B-21-2 x IR 64	0.880	0.315	0.055	4.122	0.543	-2.501*	12.051*	0.808	-0.332
IR67076-2B-21-2 x Thailand	0.123	0.123	0.023	-8.7335**	0.546	2.001	0.250	0.230	0.627
IR67076-2B-21-2 x IR 56	2.310*	-0.497*	-0.122*	-0.072	-0.512	4.501***	-3.750	2.376*	0.045
CSR 27 x TXD 306	-1.085	-0.322	-0.100	1.820	-0.653	-2.003	2.500	1.723	0.057
CSR 27 x IR 64	0.072	0.462*	0.135*	2.870	-0.523	-2.750*	-4.050	0.545	-0.075
TXD 306 x IR 56	-1.077	-0.300	-0.070	1,915	-0.464	0.453	11.500*	3.950***	0.050
IR 64 x Thailand	-0.085	0.520	-0.157*	-9.301**	-1.543	3.502**	-4.800	-0.050	0.310

***, **, * = Highly significant at P=0.001, Significant at P=0.01, Significant at P=0.05 respectively

Table 5.12 Estimates of reciprocal effects for rice traits under saline soil condition

Reciprocals	Characters								
	No of tillers	%Na	Na/K	Plant height	Spikelet fertility	Days to 50% flowering[a]	Grains/panicle	1000 Grain wt	Yield T/ha
Pokkali x IR 56	0.935	-0.285*	-0.082	-1.887	1.221	0.607	0.652	1.475	-0.565*
IR67076-2B-21-2 x CSR 27	1.450	-0.044	-0.122	-3.292	-1.543*	3.003**	-12.300*	1.200	0.137
IR67076-2B-21-2 x TXD 306	0.257	-0.090	0.032	-5.770	-1.211	0.541	-7.852	1.725*	0.023
IR67076-2B-21-2 x IR 64	0.277	-0.072	-0.120	-1.780	0.547	-0.752	9.101	-1.625	0.087
IR67076-2B-21-2 x Thailand	0.360	-0.197	-0.185	-8.457*	-1.110	-1.250	7.542	-0.575	-0.107
IR67076-2B-21-2 x IR 56	0.520	-0.177	0.087	-0.515	0.589	0.257	-18.850**	1.025	0.562*
CSR 27 x IR 64	-1.937	-0.075	-0.095	2.532	1.644*	-2.752**	-1.742	-0.900	0.107
CSR 27 x Thailand	0.400	-0.402*	-0.242	0.145	0.564	0.565	-7.950	1.270	-0.215
CSR 27 x IR 56	2.209	-0.127	0.066	6.472	0.500	-2.654**	-1.650	0.702	0.222
IR 64 x Thailand	1.545	-0.310	-0.075	-9.970*	-1.100	2.507**	-0.151	0.275	-0.055
IR 64 x IR 56	-1.292	-0.657**	-0.422	-5.322	-1.505*	2.245*	3.132	-0.525	-0.255
Thailand x IR 56	-1.322	-0.052	-0.01	14.210**	-1.122	1.759*	3.200	1.575*	0.417

***, **, * = Highly significant at P=0.001, Significant at P=0.01, Significant at P=0.05 respectively

Table 5.13 Estimates of reciprocal effects for rice traits under saline soil condition

Reciprocals	Characters			
	No of tillers	%Na	Na/K	Plant height
Pokkali x IR67076-2B-21-2	-0.315	-0.290	-0.055	-7.377
Pokkali x CSR 27	-1.180	0.045	0.095	3.632
Pokkali x TXD 306	-0.747	-0.280	-0.175	7.807
IR67076-2B-21-2 x Thailand	-0.652	0.120	0.022	-6.400
IR67076-2B-21-2 x IR 56	-0.212	-0.497*	-0.210	1.412
CSR 27 x TXD 306	1.757	-0.322	-0.330*	-1.772
CSR 27 x IR 64	-0.822	0.462	0.092	3.307
CSR 27 x Thailand	-1.862	-0.460*	-0.207*	-0.332
CSR 27 x IR 56	1.317	0.007	0.092	-3.852
TXD 306 x IR 64	-0.902	0.265	0.027	-6.240
TXD 306 x Thailand	0.450	0.785*	0.057	-1.007
TXD 306 x IR 56	0.950	-0.303	-0.327*	4.062
IR 64 x Thailand	0.311	-0.520*	-0.085	-4.870
IR 64 x IR 56	-2.137	-0.165	-0.050	-0.615
Thailand x IR 56	-0.807	-0.237	-0.031	-0.977

5.3 Conclusion

The following conclusions were drawn from this study:

1. Both additive and non-additive effects were important in the inheritance of characters studied in all soil environments. However, additive effects were more important for the traits at vegetative stage *viz* number of tillers, shoot Na^+, Na^+/K^+ ratio and plant height and both additive and non-additive gene effects were important for some of the traits measured at maturity stage of the plant *viz* spikelet fertility, days to 50% flowering, number of grains per panicle, 1000-grain weight, and grain yield.

2. Amongst the parental lines, the best general combiners for yield along with other traits were TXD 306 and IR 67076-2B-21-2 under normal non-saline/sodic condition; IR 56, Pokalli and TXD 306 under normal saline condition and CSR 27 and TXD 306 were best general combiners under sodic conditions. It has also been observed that three parents Pokalli, IR 67076-2B-21-2 and TXD 306 were good general combiners across the three environments for several traits. Pokkali had high and desirable GCA for Low Na^+, Na^+/K^+ and days to 50% flowering; IR 67076-2B-21-2 showed good GCA for plant height, Na^+, spikelet fertility and grain yield and TXD 306 for plant height, grains per panicle and grain yield.

3. Both maternal and non-maternal effect were significant with relatively larger maternal than non-maternal effects influencing the traits under both control non-saline/sodic conditions and saline conditions, and only maternal effects were important for characters measured under sodic conditions.

The results therefore indicated that more useful segregants and saline/sodic tolerant homozygous lines can be developed from the cross progenies of high and/or low general combiners. However, there is a need to consider both nuclear and non-nuclear genetic effects in devising a breeding strategy as these effects might lead to wrong impression of the levels of heritable genetic effects. This suggests further that the need exists for proper choices of male and female parents in hybridization programmes to improve the traits under selection.

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Chapter Six

Developing salt tolerant rice cultivars for irrigated ecologies of North Eastern Tanzania

An overview of the research findings

6.1 Introduction

Climatologists predict that Sub-Sahara Africa (SSA) countries will be mostly severely affected by a typical weather pattern, with drought likely to become more frequent and prolonged due to the effect of climate change increasing more salt affected areas. Accumulation of excess salts in the root zone resulting in crop yield reduction and a partial or complete loss of soil productivity is a worldwide phenomenon. The most serious salt affected problems are being faced in the irrigated arid and semi-arid regions and it is in these very regions that irrigation is essential to increase agricultural production to satisfy farmers' food requirements.

The development of improved salt tolerant materials will directly benefit the farmers by increasing their harvest in salt affected lands. Increased food production in fields with low or zero productivity not only improves the economy and well being of the poor farmers/owners of the land, but also increased the employment avenues to the local people during the croping season in addition to the improved status of the state's and country's granaries.

The goal of this current study is therefore to contribute to increasing food security in Tanzania through breeding adaptable and salt stress tolerant rice cultivars, which are adoptable by farmers. This chapter summarizes the findings from a study conducted in The North Eastern Tanzania to generate the information. The study objectives are highlighted followed by a summary of the findings and then the implications of the findings to breeding.

6.2 Recap of the objectives

To recap, the objectives of this study were to:

1. determine farmers' perceptions on both salt problems and its effect rice crop productivity as well as establishing farmers' needs and preferences for rice varieties in the targeted irrigation environment;
2. determine the extent of the salt the problem in both soil and irrigation water in the available rice irrigation schemes in the North-eastern Tanzania;
3. identify the major physiological mechanisms associated with salt tolerance in farmer-preferred native varieties and landraces;
4. determine the mode of inheritance of salt tolerance in rice under different salt soil environments.

6.3 Synopsis of research findings and implications

1. The participatory rural appraisal was conducted in Mkomazi and Mombo villages in Tanga region with the aim of understanding characteristics of rice–based farm economy, farmers' perception of agriculture constraints and variety preferences in salt affected areas of North-eastern Tanzania. The main findings of the study were:

i) Rice and maize were identified to be major staple foods and cash crops in the area but the potential for rice was higher than any other crop. Rice was more profitable, its consumption was higher than other crops and it was grown by almost all households surveyed.

ii) Rice farming has been identified as a major economic actively in the area and there was greater active participation of women than men..

iii) Soil degradation through increased salt affected soils and drought were identified as the major factors responsible for irrigated rice yield decline in both villages.

iv) Major varieties grown included: 1R56, IR54, IR64 and TXD 306 (Sarro). These varieties are high yielding but susceptible to salt damage. Salt tolerant varieties were unavailable. Furthermore, the information on the availability and the use of salt tolerant varieties is also unavailable to farmers in these communities.

v) The study revealed that most preferred traits of rice cultivars were high yield potential, aroma, early maturing, medium plant stature, tolerance to salt and drought. Improvement of these characters in new varieties for salt tolerance would enhance productivity with likely positive impact on small scale farmers' food security, incomes and livelihoods.

vi) There was no official awareness and capacity building programme to promote practices that would alleviate salt affected soil problems. People do some copying strategies as their own choice.

2. A preliminary study was carried out to understand soil characteristics in relation to salt problems and its extent in selected rice irrigation schemes, as a key step towards salt tolerant cultivar development. The following were the findings:

i) All the three types of salt affected soils (sodic, saline and saline-sodic) in the area but saline sodic and saline-sodic are dominant problems.

ii) The causes of sodicity problems in these irrigation schemes are from both weathering of the parent rock in the field (primary) and the irrigation water source (secondary).

iii) Seven out of nine studied irrigation schemes are salt affected. Soils with EC of up to 10.5 dSm^{-1} and SAR of 72 have been recorded. The results concurred with farmers complaints on the salt affected soils as a major production constraint in the area. This indicates the magnitude of the problem and point toward the importance of developing salt tolerant varieties for salt prone areas.

iv) Poor irrigation canals and management of irrigation water were the driving factors that contributed to salts accumulation hence soil degradation, therefore causing decline in productivity in the area.

v) The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. In this case the sodicity is common in irrigation water in majority of the schemes of North Eastern Tanzania. Results from water samples collected from main canals serving surveyed schemes also indicated the presence of slight to moderate sodicity (Ec_w of 0.08 - 0.47 dSm^{-1}; pH of 6.9 - 7.8 and SAR of 7.3 to 15.1). This has a significant contribution in increasing saline-sodic soils in most of surveyed irrigation schemes in the area.

These findings indicate the magnitude of the problem and highlight the urgent need for developing salt tolerant cultivars. They also imply that farmers were aware of the existing problem and concurred in their view that salty soil was a major problem that needs a serious attention, and the use of salt tolerant cultivar will be a valuable option that will improve their rice yield. Improving the existing adapted and farmers' preferred rice varieties for salt tolerance is an easy and cheap way of cultivar development and will increase the chance of adoption as farmers already know characteristics of their varieties, therefore, will be willing to plant them than introducing a completely new variety. It has also been noted that more women involvement in cultivar development, utilization of their indigenous knowledge and understanding their preferences for rice varieties may increase adoption of new varieties. However, all these should be integrated with strong official awareness programmes to improve farmers understand of the problems and implement better mitigation measures. Furthermore, efforts for prevention of the problems from developing in the currently non-salt affected areas in the region and its vicinity are highly recommended.

3. The study was established under controlled conditions to assess the salt tolerance of some rice farmers' preferred rice cultivars and evaluate the putative traits in the rice materials that contribute to the performance of a genotype under saline and saline-sodic condition. The main findings were:

i) Significant variation exists among genotypes for response to salt stress. Genotypes Pokalli, IR67076-2B-21-2 and IR 56 showed an outstanding performance in saline condition whereas CSR 27 and Nerica 2 showed good performance under saline-sodic conditions.
ii) Among the local farmer preferred varieties, IR 56 had superior performance under both saline and saline sodic conditions.

iii) The experiment also revealed that, except for IR 56 which had moderate performance under saline and saline sodic conditions all the genotypes which performed well under saline condition, had poor performance under saline-sodic conditions.

iv) Plant vigour, less injury symptoms, shoot fresh and /or dry weight, low leaf Na^+ and low Na^+ /K^+ concentrations are good indicative characteristics of a better performing genotype at vegetative stages, whereas, spikelet fertility, grains per panicle and 1000 grain weight are useful at reproductive stage. It can therefore be concluded that, these traits in combination could make good criteria for selection of salt tolerant materials under saline and saline-sodic conditions.

4. Marked environmental influences and genotypic effect for salinity and sodicity tolerance have already been established. Therefore, the study was undertaken to explain genetic mechanism governing various morpho-physiological parameters in selected Tanzania local farmers' preferred varieties and salt tolerant donors under saline and sodic soil conditions of North Eastern Tanzania. The findings were:

i) Both additive and non-additive effects were important in the inheritance of characters studied in all soil environments. However, additive effects were more important for the traits at vegetative stage *viz* number of tillers, shoot Na^+, Na^+/K^+ ratio and plant height and both additive and non-additive gene effects were important for the traits measured at maturity stage of the plant *viz* spikelet fertility, days to 50% flowering, number of grains per panicle, 1000-grain weight, and grain yield.

ii) Amongst the parental lines, the best general combiners for yield along with other traits were TXD 306 and IR 67076-2B-21-2 under normal non-saline/sodic condition; IR 56, Pokkali and TXD 306 under saline condition and CSR 27 and TXD 306 were best general combiners under sodic conditions. It has also been observed that three parents Pokalli, IR 67076-2B-21-2 and TXD 306 were good general combiners across the three environments.

iii) Both maternal and non-maternal effects were significant with relatively larger maternal than non-maternal effects influencing the traits under both control non-saline/sodic conditions and saline conditions, and only maternal effects were important for characters measured under sodic conditions

The outstanding performances of genotypes Pokalli, IR67076-2B-21-2 and IR 56 under saline salt stress and CSR 27 and Nerica 2 under saline-sodic stress environment indicated that these genotypes can be considered as useful donor for tolerance genes, therefore confirmed their usefulness in improving the tolerance of local preferred cultivar. The same genotypes Pokalli, IR67076-2B-21-2, CSR, IR 56 and a local high yielding but sensitive genotype TXD 306 were good general combiners for yield and associated traits under salt stress and non stress conditions. This indicated that more useful segregants and saline/sodic tolerant homozygous lines can be developed from the crosses progenies of these set of parents. However, differential performances of genotypes under different salt environments were observed, whereby, genotypes such as Pokalli performed extremely well under saline conditions but under-performed in saline-sodic conditions indicating the influence of salt environment on the performance of a genotype therefore suggesting that genotypes selection should be done under specific salt condition.

Genotype IR 56 appears to be a better candidate among the local cultivars under both salinity and saline-sodic stresses as it showed its ability to absorb less Na^+ and maintain high K^+ content under salinity stress, and maintained good tillering ability, number of grains per panicle and 1000 grain weight which are useful traits for selection under salinity and sodicity conditions. This genotype is among local preferred cultivar, therefore a useful candidate to be used in a salt tolerant breeding programme.

Additive effects also played a role in influencing the morpho-physiological traits in rice genotypes, and both additive and non-additive effects influencing the yield and component traits. It is possible therefore to attain farmers demand for salt tolerant and high yielding varieties through this breeding programme. Traits significantly controlled by mainly additive effects like Shoot Na^+ content and Na^+/K^+ ratio, plant height and number of tillers would be easy to fix in a breeding programme. Selection based on the trait controlled by both additive and non-additive effects will be delayed to later generations. However, there is a need to consider both nuclear and non-nuclear genetic effects as a breeding strategy as these effects might lead to wrong impression on the genetic effects. This suggests further that the need exists for proper choices of male and female parent in hybridization programmes to improve the traits under selection.

6.4 Thesis conclusion

Looking across the results of the experiments carried out, it is evident that breeding salt tolerance has potential to result in increasing rice yields that match with "green revolution" in cereals. This work has confirmed the value and potential of the salt tolerant varieties in irrigated rice farming systems of North Eastern Tanzania which may be, to a large degree, applicable to other salt prone rice irrigation systems in Tanzania and sub-Saharan Africa. It has also been confirmed that genetic variability, the foundation of breeding, exists in available rice germplasm. Selections from these germplasm alone can lead to substantial yield gains. The potential of salt tolerant varieties contribution to community well being of resource poor farmers in marginal rice irrigation in arid and semi arid environments and national economies remains high.

References

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