Effects of sodium chloride on water quality and growth of *Oreochromis niloticus* in earthen ponds

David Liti[1]*, Jonathan Munguti[2], Norbert Kreuzinger[3] and Helmut Kummer[4]

[1]Department of Zoology, Moi University, PO Box 1125 Eldoret, Kenya, [2]KMFRI Sangoro Aquaculture Station, PO Box 136 PAP- Onditi Kisumu, Kenya, [3]Vienna University of Technology Institute for Water Quality and Waste Management, Karlsplatz 13/226, A-1040 Vienna, Austria and [4]BOKU- University of Natural Resources and Applied Life Sciences, Max Emanuel Strasse 17, A-1180 Vienna, Austria

Abstract

A 2 × 2 factorial experiment was conducted between April and August 2001 to evaluate the effects of NaCl on *Oreochromis niloticus* growth and water quality in twelve 0.015 ha limed ponds. The design involved fertilizer and salt as factors with two treatments for each factor. Each salt-fertilizer combination was replicated three times and fish were not offered external food during the 98 days culture. Growth of *O. niloticus* was significantly enhanced by salt at higher fertilizer level but not at the lower fertilization level. Although salt had no direct effect on fish growth, a significant salt-fertilizer interaction was demonstrated. Water quality variables, with a few exceptions, were similar among the salted treatments. Total ammonia increased significantly with fertilization level, but the values were similar in salted and unsalted treatments at the same fertilizer level. Total nitrogen was higher in the salted than unsalted treatments while the organic matter content was lower in the salted treatments. The reasons for the better growth of *O. niloticus*, are discussed with respect to water quality variables. The present results suggest that fertilization rates of 20 kg N ha^{-1} may have negative effects on fish growth. However, presence of sodium chloride seems to reduce these negative effects.

Key words: Oreochromis niloticus, semi-intensive, soda lakes, sodium chloride.

Résumé

Une expérience factorielle 2 × 2 fut menée entre les mois d'avril et août 2001 afin d'évaluer les effets de NaCl sur le taux de croissance de *Oreochromis niloticus* et la qualité d'eau dans 12 mares chaulées de 0.015 ha. Le modèle comprenait fertilisant et sel comme facteurs, avec deux traitements pour chaque facteur. Chaque combinaison sel-fertilisant fut répliquée trois fois et nous n'avons pas offert de nourriture externe aux poissons pendant les 98 jours de culture. Le taux de croissance de *O. niloticus* fut augmenté significativement par le sel quand le niveau de fertilisant fut élevé, mais non quand ce dernier fut plus bas. Tandis que le sel n'agissait pas sur la croissance des poissons en isolation, une interaction significative entre le sel et le fertilisant fut attestée. Des variables de la qualité d'eau - à part quelques petites exceptions – furent semblables parmi les traitements salés. Le niveau total d'ammoniac augmentait significativement avec le niveau de fertilisant, mais les valeurs de ceci convergeaient chez les traitements salés et non-salés. Le niveau total de nitrogène fut plus élevé chez les traitements non-salés tandis que le composant de la matière organique fut plus bas chez les traitements salés. Ici, les raisons sous-jacentes de la croissance meilleure de *O. niloticus* sont traitées par rapport aux variables de la qualité d'eau. Les résultats actuels suggèrent que les taux de fertilisant de 20 kg N ha^{-1} peut entraîner des effets négatifs sur le taux de croissance des poissons. Cependant, la présence du chlorure de sodium semble réduire ces effets négatifs.

Introduction

Tilapia farming is an old traditional practice in some African countries (Popma & Michael, 1999), where it forms a cheap source of fish protein to many low-income communities. In these regions, poverty and lack of basic food nutrients are severe. Protein is the most deficient among these nutrients and there has been increased pressure on the exploitation of the wild fishery resources in the natural aquatic ecosystems. To ease the pressure on

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**Correspondence*: E-mail: d_liti@yahoo.co.uk

the natural systems, intensification of tilapia pond culture may be a promising approach. Tilapias thrive well on a wide range of natural food items, which are primarily of plant origin, and include living algae and the associated detritus (Fish, 1955; Bowen, 1979, 1980; Mckaye & Marsh, 1983). Most young tilapias prefer zooplanktivorous diets before turning primarily to herbivorous diets at fingerling stage (Moriarty & Moriarty, 1973; Bowen, 1982; Trewavas, 1983), and thus, are suited for culture in semi-intensive ponds. In this system, the natural food of tilapia is normally stimulated by fertilization with inorganic nutrients of nitrogen and phosphorus (Boyd, 1976; Diana, Lin & Jaiyen, 1994), a practice that is based on the assumption that the two nutrients are the main limiting factors in the stimulation of the food for herbivorous fish. However, ecological studies have indicated that soda lakes in the Sub-Saharan Africa are highly productive, and posses a unique ionic composition (Talling *et al.*, 1973). The water in these lakes is largely dominated by sodium, chloride and bicarbonate ions (Talling & Talling, 1965). It is this unique composition of ions in soda lakes that has been associated with the high primary productivity and fish yields which have been observed in the water bodies (Fish, 1955). Although this ecological information has been in existence for more than three decades, it has not yet received practical applications in semi-intensive fish-pond culture. The present study was designed to synthesize soda water in fertilized earthen ponds and to evaluate the effects of the resulting soda water on the growth of *O. niloticus* and some water quality variables. Soda water was created by addition of common salt (sodium chloride) and lime into earthen ponds.

Materials and methods

The present study was conducted in Sagana Fish Farm, which is located at 0°39′S, 37°12′E, and at an altitude of 1230 m a.s.l. It is situated 105 km Northeast of Nairobi, Kenya. Twelve earthen ponds each measuring 150 m^2 were drained and left to dry 2 weeks prior to the start of the experiment. The dry experimental ponds were limed, refilled with water and stocked with sex-reversed male *Oreochromis niloticus* fingerlings at an average weight of 32 g. Each pond was stocked at a rate of two fish per square metre. The stocked ponds were assigned to four treatments to form a two-factor analysis of variance with fertilizer and salt as factors. Each factor was split into two treatments as follows; full-dose (20 kg N ha^{-1} $week^{-1}$ and 8 kg P ha^{-1} $week^{-1}$) and half-dose (10 kg N ha^{-1} $week^{-1}$ and 4 kg P ha^{-1} $week^{-1}$) for the fertilizer factor, and salted (an initial addition of common salt at 50 kg per pond followed by weekly additions of 5 kg per pond) and unsalted for the salt factor. The full-dose fertilizer, unsalted treatment served as a control because it has commonly been used in previous studies at Sagana fish farm. The complete design with notations was as follows: FU, full-dose fertilizer without common salt; HU, half-dose fertilizer without common salt; FS, full-dose fertilizer with common salt; HS, half-dose fertilizer with common salt.

Fish in all the treatments were not supplemented with external food. Fertilization was carried out weekly with urea and diammonium phosphate. The culture took 98 days. Fish were sampled bi-weekly using a seine net and it was ensured that each sample contained over 50% of the total number of fish in each pond to obtain a better estimate of the mean fish weight. All the sampled fish were counted and batch weighed to the nearest 0.1 g using a bench scale (DS10) to determine the mean weight. Primary productivity in the ponds was determined using the free-water diurnal curve method. Dissolved oxygen values were measured at 0.25 m intervals and air-water diffusion correction was carried out using the numerical wind speed-oxygen diffusion relationship. Samples for the other water quality variables were taken on a 2-week interval using a 90 cm water column sampler (Boyd & Tucker, 1992). Water samples were taken from three different locations (near the inlet and outlet, and close to the shore along the pond length) within each pond and pooled to provide an integrated sample; a subsample was then drawn from the pooled sample for the analyses of water quality variables. The analysed water quality variables included nitrate-nitrogen, nitrite-nitrogen, total ammonia-nitrogen (TAN), soluble reactive phosphorus, total nitrogen (TN), total phosphorus, total alkalinity, total hardness, chlorophyll *a*, volatile organic solids and pH. Water quality analyses were carried out according to standard methods as described in American Public Health Association (APHA; 1989) and Egna, Brown & Leslie (1987). pH was measured by glass electrode, Hi-9024 (Hanna instruments, IL, USA). A 25 cm diameter white Secchi disk was used to measure water transparency while weather data was gathered from a meteorological station located at Sagana fish farm. Temperature and dissolved were measured at four depths (0.05, 0.25, 0.5 and 0.75 m) using Model 57 oxygen meter (YSI industries, Yellow Springs, OH, USA). The data was analysed by use of Statgraphics Plus for

Windows 2.1 Program (Statistical Graphics Corporation, 1994).

Results

The results of mean fish weights and water quality variables are shown in Table 1. Salting of fishponds at full-dose fertilizer (FS) gave significantly ($P < 0.05$) higher mean fish weight than those in the unsalted ponds at the same fertilizer level (FU). Salting of ponds at a half-dose fertilizer did not significantly ($P > 0.05$) improve fish performance over the unsalted ponds. There were significant differences ($P < 0.05$) in fish growth between the fertilizer treatments; however, no significant differences ($P > 0.05$) in mean fish weight were observed between the salt treatments. There was a significant ($P < 0.05$) interaction between the salt and fertilizer treatments. The trends for fish growth during the study period are shown in Fig. 1. The mean weights of fish in FU treatment displayed the lowest growth rate while fish growth in FS treatment was the fastest during the study period. All the treatments except FS had shown signs of growth decline towards the end of the study.

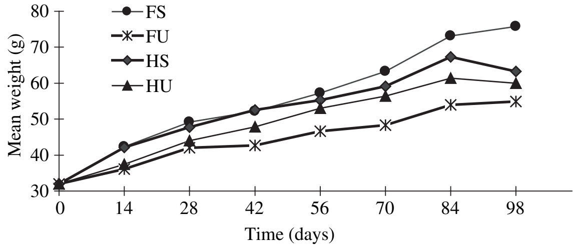

Fig 1 Growth curves of the mean weights of *Oreochromis niloticus* under different treatments during the study period. FU, full-dose fertilizer unsalted treatment; HU, half-dose fertilizer unsalted treatment; FS, full-dose fertilizer salted treatment; HS, half-dose fertilizer sated treatment.

The mean TAN values were not significantly different ($P > 0.05$) between salted and unsalted treatments at the same fertilizer level, but were significantly different ($P < 0.05$) between fertilization levels, with higher values in full-dose than half-dose fertilizer. The ranges of the individual values of TAN were 0.3–2.6 and 0.2–0.98 mg l^{-1} for full-dose and half-dose, respectively. The TAN trends for the entire period of study are shown in Fig. 2. TAN levels were high in the first 2 weeks of the experiment in all the treatments but thereafter declined for the rest of the study period. Nitrite-nitrogen displayed a pattern similar to that of TAN. Chlorophyll *a*, was

Table 1 Summary of mean values for fish growth and water quality variables (mean ± SE, pooled)

	Treatments				
Parameter	FU	HU	FS	HS	*P*
Mean weight (g)	53.4 ± 4.41^{a}	63.2 ± 4.41^{a}	75.6 ± 4.41^{b}	61.7 ± 4.11^{a}	0.047
Total alkalinity (mg $CaCO_3$ l^{-1})	67.2 ± 4.14	81.6 ± 4.85	86.3 ± 5.85	78.2 ± 6.72	NS
Total hardness (mg $CaCO_3$ l^{-1})	58.2 ± 4.08	80.0 ± 4.86	88.7 ± 4.08	81.8 ± 5.95	NS
Nitrite-N (mg N l^{-1})	0.11 ± 0.02^{b}	0.04 ± 0.01^{a}	0.11 ± 0.02^{b}	0.03 ± 0.01^{a}	0.0356
Nitrate-N (mg N l^{-1})	0.3 ± 0.05	0.2 ± 0.04	0.3 ± 0.06	0.3 ± 0.03	NS
Total ammonia-N (mg N l^{-1})	1.2 ± 0.15^{b}	0.3 ± 0.05^{a}	0.9 ± 0.16^{b}	0.3 ± 0.06^{a}	0.0000
Total nitrogen (mg N l^{-1})	5.0 ± 2.21^{a}	3.5 ± 2.21^{a}	14.9 ± 2.21^{b}	11.8 ± 2.21^{b}	0.0015
Organic matter (%)	40.1 ± 4.52^{b}	40.2 ± 4.52^{b}	21.1 ± 4.52^{a}	21.8 ± 4.52^{a}	0.0025
Chlorophyll *a* (mg m^{-3})	80.0 ± 14.0^{b}	56.5 ± 14.0^{a}	71.2 ± 14.0^{b}	31.8 ± 14.0^{a}	0.0285
Gross primary production (mg C l^{-1} day^{-1})	4.25 ± 0.52	3.7 ± 0.52	3.2 ± 0.52	3.4 ± 0.52	NS
Morning pH	8.2 ± 0.05^{b}	8.0 ± 0.09^{a}	8.4 ± 0.06^{c}	8.0 ± 0.04^{a}	0.016
Afternoon pH	9.2 ± 0.15	9.2 ± 0.09	9.1 ± 0.19	9.0 ± 0.14	NS
DO in morning (p.p.m)	3.2 ± 0.64	3.9 ± 0.78	2.8 ± 0.39	2.9 ± 0.38	NS
DO in afternoon (p.p.m)	11.3 ± 0.91	10.3 ± 0.77	10.3 ± 0.86	9.2 ± 0.88	NS
Temperature morning (°C)	22.3 ± 0.39	22.6 ± 0.41	22.3 ± 0.34	22.6 ± 0.46	NS
Temperature afternoon (°C)	26.9 ± 0.77	27.1 ± 0.63	27.1 ± 0.78	27.4 ± 0.75	NS

FU, full-dose fertilizer unsalted treatment; HU, half-dose fertilizer unsalted treatment; FS, full-dose salted treatment; HS, half-dose fertilizer salted treatment; NS, not significant. Mean values in each row bearing the same superscript letter are not significantly different at $P > 0.05$.

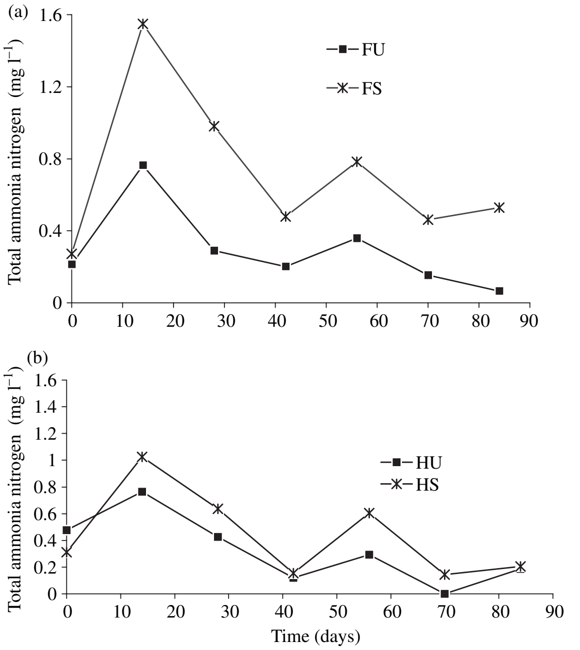

Fig 2 Trends in total ammonia-nitrogen under different treatments during the study period. Full-dose fertilizer (a) and half-dose fertilizer (b). FU, full-dose fertilizer unsalted treatment; HU, half-dose fertilizer unsalted treatment; FS, full-dose salted treatment; HS, half-dose fertilizer sated treatment.

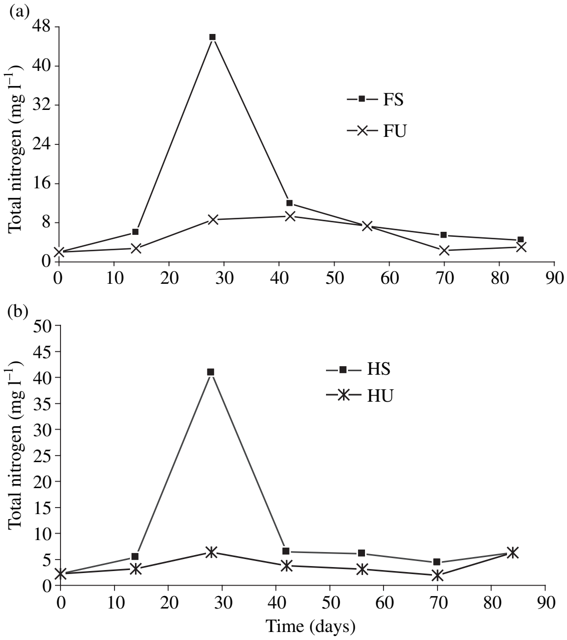

Fig 3 Trends in total nitrogen in full-dose fertilizer salted and unsalted (a) and half-dose fertilizer (b) salted and unsalted treatments during the study. FU, full-dose fertilizer unsalted treatment; HU, half-dose fertilizer unsalted treatment; FS, full-dose salted treatment; HS, half-dose fertilizer sated treatment.

significantly ($P < 0.05$) higher at full-dose fertilizer than at half-dose fertilizer level but differences between salted and unsalted treatments at the same fertilization level were not significant ($P > 0.05$). The overall mean levels for full and half-dose fertilizer levels were 75 mg m^{-3} and 44 mg m^{-3}, respectively. The interaction between salt and fertilizer for chl *a* was not significant ($P > 0.05$). Although slightly lower primary production values were recorded in the salted treatments, the differences were not significant ($P > 0.05$). Secchi disk visibility was significantly different ($P < 0.05$) among treatment means. Total organic matter was significantly ($P < 0.05$) lower in the salted than unsalted treatments. The organic matter in the salted treatments was about 50% lower than that in the unsalted treatments. TN was significantly ($P < 0.05$) higher in salted than unsalted treatments at all fertilizer levels. The overall mean values for TN were 10.4 mg l^{-1} for salted and 3.6 mg l^{-1} for the unsalted treatment. Mean values for TN in the salted treatments were approximately three to four times those in unsalted treatments. TN trends for the entire study period are demonstrated in Fig. 3. A peak occurred 30 days from the start of the experiment, which was thereafter followed by a decline for the remaining part of the study period.

Discussion

Salting of fishponds at full-dose fertilizer resulted in significantly higher mean weights of *O. niloticus* than those of fish in ponds treated at the same fertilization level but without salt. As expected, fish growth significantly increased with increasing fertilization but statistical tests did not indicate any significant influence of salt on fish growth. A significant salt-fertilizer interaction was demonstrated suggesting that the response of fish growth to fertilization was dependent on the presence or absence of common salt. Applications of nitrogen fertilizers such as urea and ammonium salts are reported to increase ammonia levels in semi-intensive culture ponds (Knud-Hansen, Mcnabb & Batterson, 1991; Boyd, 1997). Ammonia is toxic to fish and sublethal levels are known to reduce the growth of many species of fish (Colt & Tchobanoglous, 1976; Daud, Hasbollah & Law, 1988; Abdalla *et al.*, 1996). In the present study, levels of TAN at full-dose fertilizer were not significantly different between salted and unsalted treatments. However, despite the similarity in the levels of ammonia, fish in the salted treatment recorded significantly better growth than in the unsalted treatment, suggesting that common salt might have played an important role in reducing the negative effects of ammonia on fish growth.

Although there is a wealth of information on the toxicity of ammonia to fish, there are limited data on the effects of sodium chloride on the toxicity of ammonia to fish. However, it has been reported that ammonia excretion from the blood plasma of fish is effected through an exchange of NH_4^+ for Na^+ at the gill surfaces (Maetz & Romeu, 1964). Sodium is also reported to influence the secretion of large quantities of active organic compounds into the surrounding waters (Wetzel & MacGregor, 1968; Wetzel, 1968; Jüttner, 1981). The rate of secretion of these compounds was reported to be influenced by the ratio of Na^+ to Ca^{++} (Wetzel, 1969), increasing with increasing concentrations of sodium in hard waters. The secreted organic compounds are degraded by the microbial community leading to loss of the labile organic compounds and accumulation of more resistance nitrogenous compounds. The results of the present study indicated a significantly lower organic matter content and elevated levels of TN in the salted than unsalted treatment suggesting that more secretion of organic compounds had occurred in salted than unsalted treatments.

Organic compounds are known to acts as excellent chelating agents for many ions (Fogg & Westlake, 1955), and there are reports that the chelating of ions by organic compounds results in either reduction or synergic effects on the toxicity of many toxins (Redner & Stickney, 1979; Daud *et al.*, 1988). It is, therefore, possible that these organic compounds would also chelate the ammonium ions as well as the un-ionized ammonia molecules. Un-ionize ammonia is toxic to many fish species and toxicity results when fish fail to excrete this compound against a higher external gradient (Hargreaves & Kucuk, 2001). The chelating of unionized ammonia molecules by organic compounds would be expected to reduce the external gradient of un-ionized ammonia and its rate of diffusion in to the plasma and tissue of fish. This would probably form a plausible explanation for the higher growth of *O. niloticus* that was observed in the salted treatments at full-dose fertilization level despite the occurrence of similar sublethal levels TAN in salted and unsalted treatments.

At half-dose fertilizer level, calculated mean value of unionized ammonia was 0.3 mg l^{-1} NH_3 and there were no significant differences in mean fish weights between salted and unsalted treatments. This observation suggested that the growth of *O. niloticus* was not significantly affected at un-ionized ammonia levels of 0.3 mg l^{-1} NH_3. This observation is in agreement with Hargreaves & Kucuk (2001), who reported higher tolerance (0.65 mg l^{-1} NH3) to ammonia in blue tilapia raised in ponds contrary to the no effect level of 0.08 mg l^{-1} NH3 which was reported by Abdalla *et al.* (1996). These observations highlight the inapplicability of ammonia data derived from controlled laboratory experiments to highly dynamic culture systems such as fish ponds.

The loss of organic matter from live algae in the salted treatments might also have another positive implication for *O. niloticus* growth. The accessibility of algal cell contents by digestive enzymes is an important factor contributing to the good growth of an herbivorous fish (Fish, 1955; Moriarty, 1973; Getachew, 1987). The diet of adult *O. niloticus* is reported to be dominated by live algae and the associated detritus (Moriarty, 1973; Getachew & Fernando, 1989). Possession of long intestines and the occurrence of low gastric pH enable *O. niloticus* to exploit a wide range of plant materials (Getachew, 1987). However, even with such facilities, the digestibility of algae by the fish is still low and variable, and is dependent on the nature of the algal cell walls (Moriarty, 1973; Moriarty & Moriarty, 1973). The increased secretion of organic matter in the presence of common salt suggested that the integrity of the cell wall structures of the phytoplankton were affected in some way that increased their permeability to digestive enzymes. The digestive enzymes of the fish could, therefore, get access to the algal cell contents, thus making them easily digestible by the fish.

In conclusion, although application of inorganic nitrogen fertilizers in semi-intensive culture ponds is reported to increase fish yields, weekly applications of nitrogen-based fertilizers at levels of 20 kg N ha^{-1} seemed to reduce the growth rate of *O. niloticus*. Chronic levels of ammonia, which have been reported to reduce the growth of *O. niloticus* are prevalent in semi-intensive fertilized ponds. However, in the presence of common salt, high levels of fertilizer might be applied to increase fish yields in semi-intensive culture ponds without the deleterious effects of ammonia on fish growth.

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