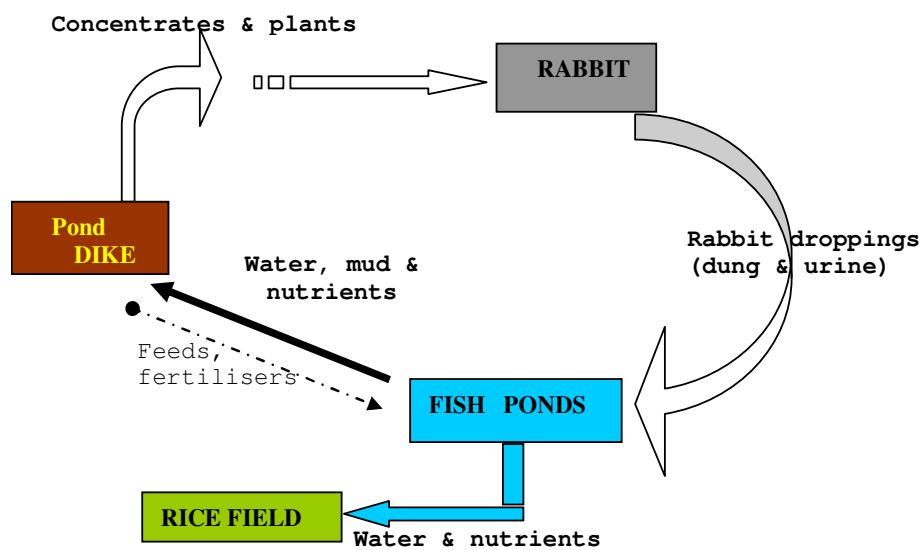


Optimisation of an Innovative System of Sustainable Production in Rwanda: The Integrated Rabbit–Fish–Rice System

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A thesis submitted to the School of Agricultural, Earth and Environmental Sciences / University of KwaZulu-Natal, in fulfilment of the academic requirements for the degree of Doctor of Philosophy in Environmental Sciences

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Abstract

Population escalation in the developing world has been associated with increased poverty, food insecurity and environmental degradation. The situation in Rwanda, with 2.82% annual population increase is no exception. The objective of the present study was to investigate an innovative integrated system of sustainable production suitable for resource-poor rural farmers, the Integrated Rabbit–Fish–Rice (IRFR) system. The study was targeted towards contributing to Rwanda government’s goals of eradicating extreme poverty and hunger, enhancing food security as well as abating environmental degradation.

Three experiments, were carried out between 2008 and 2010, and designed to fertilise pond water with rabbit droppings and boost phytoplankton production. We also used results from our previous study, conducted in 2005 in the same ponds and under similar experimental conditions, especially rabbit and fish species and age, fishpond dimensions, as well as the fertilisation mode. The fishpond effluent was re-used to irrigate rice fields rather than being discharged into the environment.

This study advocated the potential adaptation of rabbits to wetland conditions and the role of rabbit droppings as organic fertilisers in providing a better environment for fish production. On-farm resources, including rabbit droppings, were the main source of nutrients in the system. The analysis of nutrient flow revealed that 27% N and 79% P of the total nitrogen and phosphorus in fertilizing input in fishponds were supplied by rabbit droppings only. Nile tilapia *Oreochromis niloticus* were able to recover 18.5–37.6% N and 16.9–34.3% P of the total nitrogen and phosphorus inputs, the rest being accumulated in the pond water and the sediment, making them useful for soil fertilisation.

The re-use of nutrient-rich effluent in rice irrigation increased rice production, allowing a successful complete substitution of inorganic fertilisers. The irrigation also reduced environmental pollution as the water seeping through rice field was 31.8 and 83.3% less

concentrated in total phosphorus and nitrite pollutants, respectively, than was the pond water. Economically, the IRFR generated up to 597% net return over that of the rice inorganically fertilised, thereby substantiating the sustainability of the system.

Overall, it is concluded that the IRFR system works well, is readily applicable, and capable of high, diversified, and sustainable production on limited land. As such, the study demonstrates the potentialities of the IRFR system to contribute successfully to poverty reduction, and the enhancement of food security in rural areas. The system promises economic returns and is environmental friendly.

The research recommends the optimal range of rabbit density, that is, 800–1200 rabbits per hectare of pond, and the best fish stocking density, that is, 3 fish.m⁻², for a sustainable IRFR culture system.

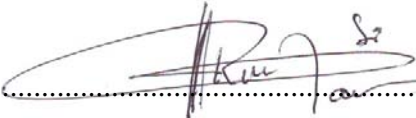
Keywords: Integrated agriculture-aquaculture system, rabbit–fish–rice system, rabbit survival, water and pond soil quality, optimisation, Flux of nutrients, nutrient-rich effluent reuse, Tilapia yield performance, cost-benefit analysis.

S. RukeraTabaro

Preface


The research described in this thesis was carried out in the School of Environmental Sciences, University of KwaZulu-Natal, Pietermaritzburg, and the field works were done at National University of Rwanda (Rwasave fish farming and research station), from August 2006 to June 2011, under the supervision of Professor Onesimo Mutanga (School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, UKZN, South Africa) and Professor Jean-Claude Micha (University of Namur, Belgium).

I would like to declare that the research work reported in this thesis has never been submitted in any form for any degree or diploma to any tertiary institution. It, therefore, represents my original work. Where use has been made of the work of other authors or organisations it is duly acknowledged within the text or references chapter.

Simon Rukera Tabaro  Date:

As the candidate's supervisors, we confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted for examination with our approval.

1. Prof. Onesimo Mutanga: Signed: Date:

2. Prof. Jean-Claude Micha: Signed:  Date:

Declaration 1: -Plagiarism

I Simon Rukera Tabaro 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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Declaration 2: - Publication and manuscripts

RukeraTabaro S.*, Mutanga, O., Rugege, D., Micha, J.-C., n.d (accepted). Rearing rabbits over earthen fishponds in Rwanda: effects on water and sediment quality, growth and production of Nile tilapia *Oreochromis niloticus L.* *Journal of Applied Aquaculture*

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Dedication

To my darling wife, *Nathalie N.M*, and our beloved children, *Sandy, Sheila, Nathan, and Norah* for their enduring and fruitful patience;

To the memory of my late parents, *Songa N. G., N'Bashyitsi G., Ngabo T. and Katarwa C.* who, regretfully, could no longer enjoy the fruits of their devotion to us;

This work is dedicated.

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1. CHAPTER ONE: General introduction

1.1 Introduction

Most of developing countries are often characterised by rapidly growing populations, a scarcity of land available for agriculture, small-scale farms, and resource-poor farmers with a lack of agrarian technology skills. These conditions result in increased poverty, food shortages, famine, and environmental degradation. Many small-scale farmers are exposed to food insecurity themselves and struggle to make a living from their small-scale farms (Edwards, 2000; Prein, 2002; Murshed-E-Jahan and Pemsli, 2011). These challenges can be at least partially addressed by applying innovative systems of production (intensive or semi-intensive) with new agrarian technologies.

However, there are certain fundamental requirements for such innovations. The long-term adoption of new technologies will always be a problem if small-scale, resource-poor farmers are convinced of the benefits of a particular technological development that would accrue to them if they adapted it to their conditions, and that they must have the skills and resources to maintain it. Whatever technology is thus proposed by developmental scientists, it must be such that the intended beneficiaries, resource-poor farmers, can be involved in its development and eventual control. This participatory approach will ensure that not only the innovation meets farmer requirements and can be sustained by their resources, but will also strengthen their existing innovative and experimental capacity and encourage their sense of ownership of the innovations (Kenmore *et al.*, 1987, in d'Oultremont, 2000). Farmers can work with experts in the field to update local technologies while generating, testing, and applying new ones as well as being trained in their use and benefits at the same time.

Innovative technologies should also be developed with larger regional, national, even global environmental sustainability in mind. This concept implies not only that development should satisfy the needs of the present generation of farmers but also should not compromise the ability of future generations to meet their own needs (World Commission on Environment and Development WCED, 1987 in Karim 2006). Natural life-support systems on earth should be sustained and the opportunity for new generations to meet their aspirations for a better life should be extended to all (Little *et al.*, 2003). Thus small-scale, marginal farmers should also be provided with enough understanding of ecological principles to ensure renewable resource use

(d'Oultremont, 2000) as well as better management practices to enhance their capacity to develop and manage technology in a sustainable way.

The type of innovative technological development with which this thesis is concerned is the integrated agriculture–aquaculture (IAA) system which, we propose, can meet the requirements for innovations for resource-poor farmers in the agrarian economies of developing countries. There is no standard model of the IAA system, but typically, it involves the waste of one farming enterprise becoming the input into another (Edwards, 1998), thus creating economic and ecological efficiency. Models are usually situation-specific, developed from local agricultural activities, and can involve, for example, rice–fish, vegetables–fish, and chicken–fish, pig–fish, rabbit–fish, or duck–fish.

Various authors have agreed on the potential of IAA systems to contribute to the world demand for food while addressing the challenges of agricultural land scarcity, poverty reduction, and the improvement of the small-scale farmer livelihoods (Edwards, 2000; Prein, 2002; Nhan *et al.*, 2008; FAO, 2010; Murshed-E-Jahan and Pemsil, 2011). Further to all these considerations, the output of such systems, particularly the fish, will make a major contribution to the nutritional needs of the rural people of developing countries because fish convert low-grade input to high-quality protein. According to the FAO (2010), fish accounted for 15.7% of the intake of animal protein by the global population and 6.1% of all protein consumed in 2007. Fish also contributed 20.1% of the animal protein consumed in low-income, food-deficit countries (LIFDCs) which have a relatively low consumption of animal protein.

Rwanda, a small (26 345 km²), landlocked country in east-central Africa (surrounded by Uganda, Burundi, Tanzania, and the Democratic Republic of Congo), is a developing country with most of the characteristics and problems associated with developing countries. It is the most densely populated country in Africa, with 384 individuals.km⁻², a total population of 10 120 000 in 2009 (NISR, 2010), and the vast majority of its population live in rural areas where they are engaged mainly in subsistence agriculture on scarce land. The average farm size per household has been estimated to be less than a hectare (0.97 ha) (NISR, 2010) and, in 2009, there were only 2 295 000 ha of arable land. Despite this scarcity, increasing pressure on the land (with resulting low fertility), a low use of enhancing inputs, and increasing problems with pests and diseases,

agriculture remains the main component of the Rwandan gross domestic product (GDP) and provides most employment (Wise, 2004). However, several constraints make it increasingly difficult for farming households to meet their food needs, and food insecurity is widespread in Rwanda. Over 90% of poor people live in rural areas (MINECOFIN, 2007) and are considered food poor. A lack of animal protein is a particular problem.

Following serious economic difficulties in the crisis of the 90s, the overall Rwandan economy had substantially increased in 2006 due to a considerable increase of food and cash crops (following an expansion of the cultivated area), an increased yield of some specific crops, strengthening exports of coffee and horticultural products, and an annual growth rate in industry of 8.1% (from 7.5% in 2001); by 2006, 71% of households owned livestock (MINECOFIN, 2007). Nonetheless, the main challenges of contemporary Rwanda include a slowing economic growth, rapid population growth (2.82% in 2009) (NISR, 2010), land scarcity (accounting for 49.5% of the causes of poverty (MINECOFIN, 2007)), and an environment permanently subject to degradation. These challenges prompt special attention to be given to the sustenance of the growing population and to progressively enhancing food security and reducing poverty. Therefore, an agricultural innovation that ensures food security; bypasses the problems of land scarcity, low soil fertility, low levels of enhancing inputs; and contributes not only to food security but enhanced nutrition as well is of great potential value. One such innovation is the intensive or semi-intensive IAA system which contributes efficiently to increasing production for poverty alleviation and ensuring sustainable livelihoods (Prein, 2002; Nhan *et al.*, 2008).

Rwanda's countryside is characterised by hills and valleys; farm dwellings and animals being on the hillsides and fishponds in the valley bottoms. This makes the integration of existing enterprises difficult, therefore new systems have to be established. Nonetheless, Rwanda has some advantages that are likely to favour the IAA system. These assets include an annual temperate and diversified climate, abundant rainwater, cheap and abundant labour, a population that has vast experience in the field of biological diversity, agriculture, and the processing of agricultural and animal products (MINECOFIN, 2007). Moreover, 10.5% of the country area is composed of marshes (278 536 ha), of which 53% are cultivated and 6% lie fallow (SHER *et al.*, 2008).

The Rwandan realities of population growth and scarce land availability led the government to establish a policy that prohibits the private ownership of marshland; instead marshes have to be allocated to farmers' associations. This strategy has served for better resource management, caretaking of crops and livestock, thereby sustaining production and conserving the environment as stipulated in the Government's Economic Development and Poverty Reduction Strategy (EDPRS: 2008–2012) with regard to agriculture and environment (MINECOFIN, 2007).

Recently, efforts towards the enhancement of food security and income generation for poor farmers have resulted in converting significant marsh areas into rice fields and building irrigation reservoirs in parts of the country that have a poor hydrographic network (that is the eastern province of Rwanda). The rice field area increased from 4 750 ha in 2001 (MINAGRI, 2004, in Kayiranga, 2006) to 15 650 ha in 2008 (SHER *et al.*, 2008), with an increase in rice paddy production from 60 000 tonnes in 2005 to 82 000 tonnes in 2008 (NISR, 2009). The potential elements for IAA systems are thus in place, but unfortunately, Rwandan rice farmers still do not exploit either rice fields or reservoirs for IAA purposes, due mainly to the fear of the risks involved in aquaculture as they lack aquaculture technical skills. Before farmers can be convinced of the benefits of IAA for them, research still needed to be done both on refining the system and establishing its profitability in order to convince farmers to adapt it.

The research on which this thesis reports was conducted on an innovative integrated system of sustainable production at the Rwasave Fish Culture Research Station (SPIR) of the National University of Rwanda (geographic co-ordinates 02° 36' 10'' S and 29° 45' 25'' E and elevation about 1625 m above sea level). This system, the Integrated Rabbit–fish–rice (IRFR) system, aims at increasing food production through the synergies of integrated farming practices that suit resource-poor rural farmers (Figure 3.1). These rabbit, fish, and rice enterprises are sequentially linked and depend on the recycling of sub-products of components to enhance the production of others. More specifically, rabbit droppings (from rabbit hutches built over ponds) fertilise pond water and boost plankton production for the consumption of the fish with which the ponds are stocked. The rabbit droppings, together with fish faeces, enrich the pond water with nutrients. Thus, the enriched pond water is used as effluent to irrigate rice in adjacent rice fields.

1.2 Research hypothesis

The leading hypothesis of the study being reported on was that the waste outputs of the rabbit and fish farming components of an IAA system interact, thereby increasing the production of one or both components and enriching the effluent sufficiently in nutrients to enable it to replace inorganic fertilisers otherwise needed for rice production.

1.3 Research objectives

The main focus of the research was to contribute to the development and optimisation of the complex integrated system, composed of three levels of production, which are both sustainable in management and environmentally friendly.

Specifically, the study pursued the following objectives:

- a) Determine the overall effect of rabbit droppings on pond water physico-chemistry and primary productivity for a better environment for the fish Nile tilapia (*Oreochromis niloticus* Linnaeus);
- b) Identify all intervening resources, describe their flow within the system, and characterise the role of pond effluent in fertilising rice fields;
- c) Optimise the density of rabbit in relation to maintaining sustainable production of all components of the integrated rabbit–fish–rice (IRFR) system;
- d) Investigate the flow of nitrogen and phosphorus nutrients in the IRFR system and consequent production of each component of the system, and
- e) Determine the production performances and profitability of the IRFR system through the cost-benefit study of each component versus that of the whole system.

1.4 Outline of the thesis

The thesis has eight chapters, organised as follows

- Chapter 1, The general introduction places the research topic in context: global concern for developing countries (with regard to poverty, hunger, environmental degradation, inadequate resource management, together with the probable causes of these). The chapter proposes a type of integrated agricultural-aquacultural activity that can contribute towards the improvement of poor farmer livelihoods, describing the specific needs of Rwanda. Finally, the chapter presents the overall and specific objectives of the research and highlights the methodological approach that was followed. The details of methods and materials are presented in each chapter.
- Chapter 2 This chapter reviews the literature on conditions for the rearing of rabbits in wetland conditions and their role in fertilising fields in an IAA system producing fish and rice.
- Chapter 3 Chapter 3 investigates the overall effect of rabbit dung on the physico-chemical quality of pond water, plankton development, and fish growth and production.
- Chapter 4 The effect of rabbit dung is studied using different fish stocking densities, focusing mainly on the analysis of the resource flow throughout the IRFR system. Major nutrient sources likely to fertilise the tilapia pond and the role of pond effluent as an organic fertiliser for rice fields are also highlighted.
- Chapter 5 Data collected during all the planned experiments are reviewed for the identification of an optimal rabbit density suitable for a sustainable IRFR system.

Chapter 6 Chapter 6 describes the nutrient flow linking all sub-systems of the integrated system with the purpose of quantifying the mass flow of nitrogen and phosphorus nutrients using the mass balance approach.

Chapter 7 This chapter presents an assessment of the growth, yield performance, and profitability of rabbits, Nile tilapia, and rice paddies as separate sub-systems and as an IRFR system as a whole in tropical semi-intensive farming.

Chapter 8 An overall discussion of the research is presented and compared with the available findings and theories from the literature.

Each chapter was written as a discrete research article, therefore there will be some overlap of content and references.

**2. CHAPTER TWO: Rabbit rearing as a potential nutrient provider
for fishponds and rice fields in an integrated agriculture-
aquaculture system (IAA): A review**

2.1 Introduction

Rabbit breeding is practiced in almost all developing countries as an affordable source of animal protein for humans and as a contributor to the household economy. Rabbits are raised generally for home or commercial meat production, as laboratory animals, and as breeding stock (Adams, 1990). In addition, rabbits generate family income through sales and employment, and supply manure that improves soil fertility for agronomy (Lukefahr, 2008). Historically, rabbit meat has been considered the dietician's choice for health-conscious meat consumers; rabbit meat is low in fat compared to chicken, mutton, beef, and pork (Kumar and Ayyapan, 1998). Besides meat, which is unequivocally the main goal of rabbit production, some species of rabbit (for example Angora) are very well known for pelt and fur production as an important by-product of meat production. For example, the Hyline Californian species is important for the production of excellent carcasses, thick pelts, fur and the white meat for which it has been renowned for a long time.

The rabbit's performance traits, including its nutritional preferences, its prolific breeding rate, and its broad environmental adaptability have been widely documented (Marai and Habeeb, 1994; Marai *et al.*, 2001; Lukefahr and Ruiz-Feria, 2003; Marai and Rashwan, 2003; Marai *et al.*, 2003; Marai and Rashwan, 2004; Lukefahr, 2008). However, few studies have investigated the direct integration of rabbit production with aquaculture activities, an exception being Breine *et al.* (1996), due probably to the vulnerability shown by early-growth-stage rabbits (very young and weanling) to humid and cold environments. Despite this vulnerability, early studies on the utilisation of rabbit dung as organic fertiliser for ponds, as well as on the rearing of rabbits housed above fishponds, showed that rabbit droppings create a good environment for phytoplankton and filter-feeder fish such as the Nile tilapia (*Oreochromis niloticus*, Linnaeus). Rabbit dung causes low water turbidity when compared to sheep manure, thus promoting better autotrophic production through nutrients supplied to pond water (Franco, 1991).

The present chapter reviews the characteristics of rabbit rearing in general and rabbits' environmental requirements for the integration of their production with pond aquaculture, a system which is most likely to be developed in humid areas. It was assumed that the direct integration of rabbit production with aquaculture might produce a nutrient-rich effluent that could

efficiently fertilise other crops through irrigation. This complex integration is likely to contribute more in the way of food production than the diverse aquaculture farming systems that are known to have relevance for the poor farmer and is equally likely to contribute substantially to rural development through an improved food supply, employment, and income generation (Edwards, 2000).

2.2 Rabbit husbandry: requirements and importance for poor rural households

2.2.1 Generalities

Rabbit husbandry is considered a relatively easy method for generating income through the sale of meat, pelts, and fur in some countries, while constituting an excellent source of animal protein for human consumption. As it is a small animal, rabbit rearing requires few inputs (low investment regarding the stock, buildings, and other equipment) (Lebas *et al.*, 1996). Additionally, its diet is composed of fibrous feed; therefore, it does not compete directly with humans for food and hence the rabbit is highly complementary to other backyard animals and small ruminants (Lebas *et al.*, 1996). It utilises forage sources not otherwise used, such as kitchen scraps and other homestead by-products. The above features make the rabbit suitable for sustainable small-scale rearing in rural areas.

Based on virtues of the rabbit observed in developing countries such as Mexico, Ghana, Cameroon, Egypt, and China, rabbits are advocated by various scientists as having extreme production potential in developing countries (Owen, 1976, in Lukefahr, 2008).

Lukefahr (2008) developed a rabbit production model “the small-scale rabbit production model (SSRPM)”, based on the fact that rabbit breeding for meat production profoundly depends upon ecological, economic, and sociological factors. These factors are expected to lead to success in the feasibility, design and implementation, monitoring and evaluation of rabbit rearing; it also includes factors such as genetic factors, diet quality, health care, and material for rabbit housing.

The advantages of rabbit rearing in largely agrarian economies based on small-scale farming by resource-poor farmers are many. Rabbits allow for the low-cost rearing of meat in small quantities, using on-farm resources to promote food security for resource-poor farmers alongside intensive or commercial-scale productions. Furthermore, rabbit husbandry is easily integrated with agriculture as the diet of rabbits is based on by-products from feedstuffs cultivated in gardens. The integration involves the planting of legumes, trees and forage species which enrich the soil with nitrogen and protect the environment; these include *Leucaena*, *Caliandra*, and *Stylosanthes*. According to [Little and Muir \(1987\)](#), in [Little and Edwards \(2001\)](#), smallholder farmers prefer rabbits over pigs, chickens and cattle on a large scale because the latter require large investments and high standards of management in addition to some religious and social constraints. They also compete with the human population for food.

Knowledge of rabbit requirements should be imparted to such farmers by extension workers through a participatory approach; the following sections develop some key knowledge of a “rabbit farmer curriculum”.

2.2.2 Rabbit reproduction

The rabbit has a high rate of reproduction defined by a high number of young per doe per unit of time, litter size at birth, survival rate of the young and interval between kindling. Farmers can, therefore, improve these characteristics by the careful management of does, rearing them in an environment appropriate to both does and young so as to stimulate feed intake and suckling by providing a balanced, concentrated feed to the does when first serviced. Does should be serviced as soon as they reach 80–85% of the mature weight for the breed, or earlier for females fed an extremely well balanced ration ([Lebas *et al.*, 1996](#)). [Hartman and Petersen \(1995\)](#), cited by [Rommers *et al.* \(2010b\)](#), advised imposing a feed restriction on does during the rearing period of their litters. These authors reported a positive influence on the body weight gain and production performances of the litters of does with restricted feed allowances during the rearing period. This influence was observed from the second litter onwards and was reported to prevent obesity and reduce feed costs.

However, doe performance is impaired by hot climates as the latter cause heat stress in rabbits. [Guillén *et al.* \(2008\)](#) reported that rabbit doe productivity is impaired when lactation is extended in successive reproductive cycles. This is due to does' inability to recover properly under heat stress conditions, the latter being the condition when the temperature–humidity index (THI)¹ is higher than 28.9 ([Marai *et al.*, 2003](#)). This is an important consideration if rabbits are reared in a hot and humid climate such as is the case with most developing tropical countries including Rwanda.

2.2.3 Rabbit feed consumption

Rabbits are mainly herbivorous, consuming a large variety of wild grasses with high roughage content and therefore posing limited competition to other domestic animals and humans for similar foods. Acceptable rabbit production performance can be obtained using greens such as weeds, tree leaves, tropical legumes, grass forages, vegetable tops and many others ([Lebas *et al.*, 1996](#)). [Adams \(1990\)](#) and [Lebas *et al.* \(1996\)](#) recommend a complete and balanced ration and a variable diet according to sex and maturity for best results in rabbit husbandry. A complete ration should contain sufficient protein (amino acids), carbohydrates, fats, minerals and vitamins for maintenance and growth ([Adams, 1990](#)). Recently, [Tam *et al.* \(2009\)](#) observed that rabbits increased their feed intake and growth rates when stimulated by a dietary supplementation of paddy rice to a basal diet of water spinach.

Rabbit concentrate costs should be reduced by supplementing their diet with leaves, agricultural by-products, and kitchen waste ([Le Thu Ha *et al.*, 1996](#); [Bamikole *et al.*, 2005](#); [Tam *et al.*, 2009](#); [Radwan, nd](#)), including soapstock of oil palm, molasses-rich blocks, mulberry leaves, paddy rice and dried cow manure. However, while many feedstuffs are useful for rabbit nutrition, (for example mulberry leaves), to replace completely balanced feeds for rabbit does, [Radwan \(nd\)](#) found that feed supplementation with digestive wastes, that is dried cow manure, resulted in decreases in final rabbit weight, feed intake, and food conversion efficiency due to the

¹ $THI = db^{\circ}C - [(0.31 - 0.031 RH) \times (db^{\circ}C - 14.4)]$

where db[°]C is dry bulb temperature in Celsius degrees, and RH is relative humidity in percentage.

Marai, I., Ayyat, M., Abd El-Monem, U., 2001. Growth performance and reproductive traits at first parity of New Zealand white female rabbits as affected by heat stress and its alleviation under Egyptian conditions. *Tropical Animal Health and Production* 33, 451-462.

palatability of the manure. Rabbit feed consumption can, thus, be seen to favour the rural poor because of the easy availability of feed that is acceptable if not optimal.

2.2.4 Rabbit housing system must ensure welfare of the rabbit

Domestic rabbits are deprived of the protection of burrows which normally provide the rabbit with a cool refuge, adequate humidity, harmless ventilation and protection from noise. Thus the new housing should provide a suitable environment, that is, one that ensures that rabbits are not exposed to high temperatures as this is the most important factor in rabbit rearing (Le Thu Ha *et al.*, 1996). Even though cages are the most popular housing system used, they expose animals to high temperatures during the hot season, causing the animal to modify body heat losses by stretching out the body, pricking up the ears, dispersing themselves (in the case of young rabbits), modifying the breathing rate, and changing their peripheral temperature (Finzi *et al.*, 1992; Lebas *et al.*, 1996; Marai and Rashwan, 2004). The latter behaviours impair rabbit growth and cause the death of weak ones.

Rabbit housing should be modified as far as possible to accommodate the need for a cooler environment. Fortunately, rabbits have an enormous adaptability to exist in conditions ranging from tropical to arctic, utilising varied diets, and they can adapt to intensive as well as to extensive rearing systems (Sandford, 1992, in Marai and Rashwan, 2004). According to Lukefahr (2008), rabbit housing should be constructed in local and renewable materials such as wood, mud, stone and concrete. The use of welded wire, however, seems inescapable, as it ensures easy hygiene maintenance, especially when rabbits are raised in a hutch with suspended floors or when they are reared in direct integration with fish for an ecologically friendly and sustainable production system (Lukefahr and Preston, 1999).

A high rabbit rearing density is reported to impact negatively on rabbit welfare. Weber and Van der Walt (1975), in Marai and Rashwan (2004), observed that crowding causes aggressiveness in rabbits and they bite one another when newly put together although successive litters live calmly together. In such conditions, does in late pregnancy may also kill the young. Adams (1990) pointed out that rabbits would not perform well if they are crowded and, therefore, advocates one square foot (0.916 m²) of floor area for each pound of rabbit body weight (0.45 kg).

Experiments carried out in Rwanda (Van Vleet, 1997) led to the recommendation of a minimum of one square metre for a breeding doe with its offspring and half that area for growing rabbits. Van Vleet (1997) also advised the increase of the floor size by 50% of these figures, arguing that rabbits in larger cages seemed to maintain better health. Fortunately, studies on stocking density and housing showed that there are no consistent effects of rearing density on food use efficiency, weight gain, mortality, or agonized behaviour of weanlings of 4–11 weeks (Lukefahr *et al.*, 1980 quoted by Marai and Rashwan, 2004).

Under appropriate guidance, resource-poor farmers should have no difficulty providing appropriate housing for their rabbits mostly due to general poverty but they also lack sufficient knowledge about rabbits ecological and health requirements. The welded wire might be the biggest challenge.

2.3 Environmental requirements in rabbit husbandry

The domestication of rabbits is so recent that several problems met in housing them are explained by their wild behaviour. The changes in domestic rabbits' behaviour compared to that of their wild relatives shows that the stress caused by an unfamiliar environment, in association with humans, is a major contributing factor. In their wild state, rabbits require a peaceful environment if they are to avoid seeking refuge in their burrows which are not only refuges in case of noise but also a resting area where temperature and humidity are more constant than outside during the day (Marai *et al.*, 2001; Marai and Rashwan, 2004). In captivity, this peaceful environment is best replicated by providing rabbits with as large a living space as possible.

Environmental factors play a major role in rabbit reproduction. Doe performance under heat stress is impaired (Marai *et al.* 2002; Marai and Rashwan, 2004; in Guillén *et al.*, 2008). Guillén *et al.* (2008) reported that a hot climate reduces energy intake, milk production, litter size and growth, doe weight, as well as increasing kit mortality. Marai *et al.* (2001) observed that a hot climate not only reduced rabbit doe productivity but also affected growth performance. Mortality due to heat stress accounted for 73% rabbit mortality, but, under a cooling regime, mortality stood at 6%, taking into account losses due to conception rate, litter weight and pre-weaning mortality. Rabbits should be provided with cool drinking water as a way of alleviating heat stress.

In addition, resource-poor farmers might be able to put thatch under a metal roof or make the roof of wood.

The most important parameters influencing rabbits' physiological stress are temperature, humidity and ventilation. In addition, rabbit nutrition as well as housing-hygiene and odour have optimal values which should be adhered to. These have obvious implications for farmer training.

2.3.1 Temperature

Rabbits have a constant body temperature, therefore heat production and loss determine body temperature. Ideally, rabbits should be reared in well-ventilated sheds with an ambient temperature of between 10 and 25°C as the optimum (Lebas *et al.*, 1996; Marai and Rashwan, 2004), with a comfort zone of 21°C (Marai *et al.*, 2001). A low ambient temperature (below 10°C) causes adult rabbits to diminish their exposed body surface area and to lower their ear temperature. They also fold the ear pinnae to avoid the internal surface from coming into contact with hot air. During periods of high ambient temperatures above 25°C), rabbits stretch out to lose as much heat as possible by radiation and through convection by increasing their ear temperature. Heat dissipation is carried out by altering the breathing rate so as to increase evaporation of the moisture content of the respiratory air by the nasal mucosa and the ear (Marai *et al.*, 2001). This regulation seems to be no longer possible when the temperature is above 35°C, as rabbits can no longer regulate their body temperature and heat prostration sets in. Rabbits react by reducing feed intake and increasing water consumption in order to survive (Marai and Habeeb, 1994, in Marai and Rashwan, 2004).

Heat stress in rabbits can be alleviated by various practices, including the use of vitamin C, according to Verga (1992), in Marai and Rashwan (2004); offering of cool water, (Marai *et al.*, 2001); and by dietary supplementation with 2% protein above NRC level and vegetable oil (El-Rahim *et al.*, 1994).

Various authors studying the impact of temperature and photoperiod on reproduction physiology, noted that ejaculate volume and sperm cell concentration fall when the rabbit is exposed to temperatures of 33°C and higher (Olufa, Bogart and McKenzie, 1951 in Lebas *et al.*, 1996; Marai

et al., 2003). Better mating is obtained when there is at least 12 hours of daylight; mating percentage is lower for shorter periods of daylight. Reproductive rabbits need to be reared during much longer periods of daylight (16 hours), females together with males (Guillén *et al.*, 2008). In addition, seasonal change also impacts on rabbit reproduction, limiting the breeding season. For example, in sub-tropical regions the breeding season is limited to being from September to May (Marai *et al.*, 1996, in Marai and Rashwan, 2004). Young rabbits once produced have reasonably good fat reserves which help them to maintain body temperature if they huddle against each other to reduce heat loss. The ambient temperature should be at least 28°C.

2.3.2 Humidity

Rabbits are sensitive to very low humidity that is below 55%, the optimum humidity level for successful production being between 60 and 65% (Franco, 1991; Lebas *et al.*, 1996). The least desirable aspect of humidity is an abrupt change in its level, as this is likely to stress rabbits, even when the temperature is moderate. Research conducted on the effect of housing on reproduction and growth (Suc *et al.*, 1996) showed that underground housing systems were markedly superior to the conventional cage system. This was due to cages having the highest daytime temperatures (29.4–30.5°C) and the lowest humidity (74.2–77.6%). Cages led to 20% lower weights of growing–fattening rabbits, 23% lower growth rates, 9% lower birth rate and 36% lower weaned and survivor rates (69% vs. 86%) when compared to underground shelters which were characterised mostly by lower temperatures (average 25.2–26.9°C) and higher humidity (78.9–81.5%).

The combination of humidity and temperature has been reported to influence rabbit welfare negatively. Any deviation in climatic and managerial conditions from the optimum for rabbit production may result in abnormal behaviour and inhibited production (Marai *et al.*, 2001, 2003; Marai and Rashwan, 2004). For example, at high levels of humidity, temperatures lower than 28°C are likely to induce rabbits to dissipate as much heat as possible, a phenomenon that depresses feed intake and utilisation, as well as disturbances in the water, protein, energy and mineral metabolism balances. The latter changes result in impairment of rabbit production and reproduction (Marai *et al.*, 2003; 2005).

Lebas *et al.* (1996) observed that the rate of reproduction dropped during the wet season of the tropical climate (high temperature and humidity). The reproduction period depends upon both temperature and daylight hours (seasonal), combined with the availability of feed. Temperatures above 30°C reduce the bucks' sexual urge (Lebas *et al.*, 1996) The above observation suggests, in general, that in Rwanda, where the climate is defined by a wet season of almost six months of the year, rabbit does and kits should preferably be raised in housing that allows for low humidity levels, while only growing rabbits should be reared in rabbit hutches in integration with fish-culture. Small scale farmers would, thus, need particular assistance in understanding the effect of temperature fluctuation on rabbits, as well as in adjusting to the needs of rabbits in relation to temperature and humidity.

2.3.3 Ventilation and daylight length

The ventilation of rabbitries is important to evacuate harmful gases such as carbon dioxide (CO₂), ammonia (NH₃), Hydrogen sulfide (H₂S), and methane (CH₄), , , excreted by rabbits, as rabbits are sensitive to air quality. In fact, rabbitry gases favour most rabbit diseases, especially the respiratory ones: for example, the contagious snuffles (Marai and Habeeb, 1994). The rabbitry should be rid of excess heat, humidity and odours, and at the same time, replenished with oxygen. The ventilation should be moderate but can vary enormously depending on the current climate, housing system, and the population density. Optimal ventilation, expressed as the amount of air per kilogram rabbit biomass, must take into consideration climatic parameters, including temperature, air speed, and humidity.

A balance should be established between air speed and temperature as advised by Lebas *et al.* (1996), who observed respiratory troubles when the air movement in the rabbitry was too slow, thus allowing a high temperature to develop. The reverse situation was responsible for rabbit gut occlusion, due to a high air circulation that cooled the rabbitry too much leading to rabbit mortalities.

Efficient ventilation systems should provide air with a circulation rate of 2–3 m².kg⁻¹.h⁻¹(m² of air and kg of live weight) (Eschborn, 1985). In the case of high ammonia levels (20–30 ppm) resulting from the decomposition of litter in the rabbitry, increasing the ventilation rate is

recommended to prevent the accumulation of bacteria such as *Pasteurella* and *Bordetella*, which may enter rabbits via the respiratory pathway. The maximum permissible NH₃ content in the air is 5 ppm (Lebas *et al.*, 1996).

Most productive and reproductive traits are affected by the duration of daylight, as reported by Marai *et al.* (2003) and Marai and Rashwan (2004). The duration of daylight, together with temperature and humidity, is the biggest influence upon the biological functioning of rabbits and results in the impairment of reproduction and production, thus reducing the breeding season to September– May in the northern hemisphere. In tropical climates, variations in the duration of daylight are not as influential as temperature but cannot be excluded.

2.3.4 Nutrition

Rabbits are monogastric, herbivorous animals, but the presence of microflora in the caecum, and the coprophagy phenomenon, enable them to consume a large variety of feeds. The bulk of rabbit feed comprises grass, cereal by-products, kitchen waste, and brewers' waste. As with other monogastric animals, the undigested contents of the caecum are usually sent to the colon, where they form soft pellets called 'caecotrophes' which are richer in proteins (29.5 vs.13.1 %) and minerals (10.8% vs. 8.9%) than hard pellets. Contrarily, the hard pellets contain more fibre and fat than the caecotrophes (Lebas *et al.*, 1996; Kumar and Ayyapan, 1998). Caecotrophes are directly recovered by the rabbit when expelled from the anus, whilst the hard pellets are ejected as droppings.

Dietary fibre is recommended in diets of growing rabbits to avoid caeco-cholic digestive disturbances but the diet should incorporate a balanced supply of low- and highly digestible fibre important in reducing the risk of diarrhoea and mortality (Gidenne; 1997, 2003). This is often done by adding agro-industrial by-products, such as bran and pulps to rabbit feeds, which supply a high level of digestible fibre (hemicellulose and pectins). The digestible fibre content needs to be balanced by poorly digestible fibre and lignocellulose, mainly found in husks; sunflower, soybean cake, coconut palm can be supplied correctly in this regard. The dietary fibre level also affects the digestibility of other nutrients in the diet, influences growth rate and the chemical composition of the rabbit's body in the growing phase (Spreadburry and Davidson, 1978; Parigi-

Bini *et al.*, 1994, in Rommers *et al.*, 2010a). The dietary fibre is also used to stimulate stomach development, therefore, increasing feed intake capacity during the reproduction period.

The intake of feed and water depends on age, stage of production, type of food and the type of rabbit. For example, at four weeks of age, a young rabbit eats a quarter of the amount an adult eats but its weight is only 14% of the adult's (Lebas *et al.*, 1996). The required nutrients in rabbit feed vary mostly with the stage of production (Table 2.1) as given by Adams (1990) and reported by Lebas (1989), in Lebas *et al.* (1996).

Table 2.1: Recommended chemical composition of feeds for intensively reared rabbits of different categories

Components of feed, assumed to contain 89% dry matter	Growing rabbit (4-12 weeks)	Lactating doe	Peri-weaning	Mixed (maternity + fattening)
Crude protein(%)	16	18	15	17
Digestible protein(%)	11.5	13.3	10.8	12.4
Energy and bulk				
Digestible energy (MJ.kg ⁻¹)	10.50	11.13	10.08	10.71
Metabolisable energy (MJ.kg ⁻¹)	10.00	10.58	9.58	10.16
Fats (%)	3-5	4-5	3	3-4
Crude fibre (%)	14	12	16	14
Indigestible crude fibre (%)	12	10	14	12
ADF (%)	18	14	20	18
Ratio digestible proteins/ digestible energy (g/1000 kcal)	45	51	46	48

Source: Lebas (1989) extracted from Lebas *et al.*(1996) Energy has been converted into Megajoules: 1kcal = 0.0042 MJ

The environment plays an important role in rabbit feeding. Feed intake needs to be linked to temperature and humidity to cope with rabbit energy needs. Eberhart (1980), in Lebas *et al.* (1996), reported that as temperature rises, so the number of solid and liquid meals consumed in 24 hours drops (Table 2.2). Finzi (1992) stated that rabbits are resistant to hunger and more or less resistant to thirst but that any reduction in the water required was likely to reduce the dry matter ingested, therefore decreasing the production performance. The authors showed that the decline observed in ingestion of meals due to the environment modified the various ingestion and excretion ratios and can serve to identify thermal stress in rabbits.

Table 2.2. Changes in feed and water intakes with dependence to the environment

Ambient temperature	5°C	18°C	30°C
Relative humidity	80	70	60
Pelleted feed eaten* (<i>g/day</i>)	182	158	123
Water drunk (<i>g/day</i>)	328	271	386
Water/feed ratio	1.80	1.71	3.14
Average weight gain (<i>g/day</i>)	35.1	37.4	25.4

* Balanced pelleted feed containing 20 percent crude protein and 11 percent crude fibre, rich in protein and energy.
Source: (Eberhart, 1980 in Lebas *et al.*, 1996)

2.4 Rabbit–fish integration

Rabbits are a rustic species most suited to small-scale farming and integrative systems. Moreover, rabbits are successfully raised under limiting or harsh conditions as they never require vaccination or antibiotics, dewormers, coccidiostats or other prophylactic drugs (Lukefahr, 2008). Rabbits are known to be healthy and productive, attributes that confer on rabbits the quality of being promising for resource-poor and smallholder farmers. However, rabbits are vulnerable in regions afflicted by myxomatosis and in the case of any first-time outbreaks of such epidemics, results can be devastating (Lebas *et al.*, 1997).

Ecologically, the above attributes prompt the use of rabbits in integrated systems where they constitute the major source of nutrients to the system. The integration practices imply nutrient recycling that protects the environment; if rabbit manure is used it increases the soil's water-holding capacity, and fertilises legume forage that fixes nitrogen into the soil, and protects the environment. Legume forage, in turn, serves to feed rabbits but they can equally be fed on formulated nutrient-rich pellets. Similarly, integrating rabbit production with aquaculture allows for the recycling of nutrients in the production of plankton, a natural food for filter-feeder fish such as Nile tilapia. Various authors have reported that rabbit manure has been considered as a medium for horticulture, nursery plants in greenhouses, vermiculture, and Muscovy duck production (Rodriguez *et al.*, 1995; Finzi and Amicci, 1989, in Lukefahr, 2008).

Rabbits fed on balanced concentrates and raised on a mesh floor excrete from 25 to 400 g of faeces and 0.5 to 0.8 litre of urine per mother–cage per day, depending on the production intensity (Lebas *et al.*, 1997). These excreta are a rich source of inorganic nitrogen, phosphorus, cellulose and lignin, and contain several other nutrients (Franco, 1991; Kumar and Ayyapan, 1998). McCroskey (2001) indicated that rabbit droppings have about 3:1.5:0.3 of N:P:K and are much richer in nutrients than ordinary farm manure (Table 2.3) which at most contains 0.4–0.6% each of the main fertiliser components, N, P₂O₅, and K₂O (Lebas *et al.*, 1996).

The P content of rabbit excreta has been found to be higher than that of other animal manure used in fishpond fertilisation (Little and Muir, 1987; Franco, 1991). Rabbit manure contains the highest percentage (Table 2.3) of nitrogen and potassium (McArdle 1972 and Dhaubhadel *et al.*, 1992, in Lebas *et al.*, 1996).

Table 2.3: Approximate N, P and K values of different animal manure

Animal	Manure (Tonnes per 1000 pounds live weight)	Nitrogen %	Phosphoric acid %	Potash %
Dairy cow	26.40	0.57	0.23	0.62
Beef steer	--	0.73	0.48	0.55
Horse	--	0.70	0.25	0.77
Swine	35.20	0.49	0.34	0.47
Sheep/goat	13.20	1.44	0.5	1.21
Rabbit	9.24	2.40	1.40	0.60
Chicken	9.90	1.00	0.80	0.39
Duck	--	0.60	1.40	0.50

Extracted from (Lebas *et al.*, 1996; Van Vleet, 1997).

All the above reasons converge to support the potential success of the rabbit and its importance in integrated farming systems for income generation through meat, pelt and fur production, soil fertilisation for cropping, and water fertilisation for aquaculture undertakings. Nevertheless, the latter interest has not received much attention from researchers (Breine *et al.*, 1996). Integrated rabbit–fish integrated farming is still at an experimental stage, even though it seems to display a

considerable potential in Rwanda, (Van Vleet, 1997), and in Cameroon, Bangladesh, and Thailand where the system is being undertaken.

Integrated rabbit-fish farming is based on the principle that fertilised water develops a marked quantity of phytoplankton and zooplankton – the natural diet of most fish species produced in aquaculture. The first data obtained on this issue (Franco, 1991; Breine *et al.*, 1996; Van Vleet, 1997), confirmed that rabbit dung application in ponds increases phytoplankton abundance, indicating that it has a notable impact on primary production. Rabbit dung has led to 5.1 times the growth of Nile tilapia observed in, non-fertilised ponds (Breine *et al.*, 1996). Van Vleet (1997) reported a net yield of about 6.1 t.ha⁻¹.yr⁻¹ of the same species.

Rabbit dung causes low water turbidity compared to sheep manure, promoting better autotrophic production by supplying considerable quantities of soluble nitrogen and phosphorus (Franco, 1991). However, fishponds receiving these quantities of nutrients are soon overloaded, depending on the rabbit manure load supplied to the ponds or on the density of rabbits raised over the ponds. The pond water must, therefore, be diluted to restore good respiratory conditions for aquatic organisms reared in the ponds. The pond effluent needs good management to protect the environment instead of being discharged and polluting natural rivers.

2.5 Rice–fish integration system

Among all cereal crops, rice production is preferred for direct integration with fish as it can be grown in a wide range of ecosystems, including rainfed lowland and upland, irrigated lowland and deepwater conditions. In addition, rice is adapted to periodic submergence under water, unlike other cereals, due to its capability of transporting oxygen to the roots through its aerenchyma in the stem (Frei and Becker, 2005c). The submergence type of irrigation has the advantage of promoting water percolation, recharging groundwater, and suppressing weeds.

Fish rearing in rice fields is a 2000 year-old practice that is the most promising alternative to rice mono-cropping. Adding fish to rice-field ecology helps increase rice production and generates

social, economic and environmental benefits [Costa-Pierce \(1992\)](#), [Xiao \(1995\)](#), [Halwart *et al.*\(1996\)](#), [Rothuis \(1998\)](#), and [Bandyopathy and Puste \(2001\)](#), [Mohanty *et al.* \(2009\)](#) The beneficial aspects of rice-fish integration systems hinge on the principles of water conservation, soil improvement, and biological control, as well as maintaining sustainable production. This system allows for the optimisation of water and land use without bringing about environmental degradation. According to [Cagauan *et al.* \(2000\)](#), fish cultured in paddy fields convert and recycle the available material and energy into fish production, accelerate the productivity of the paddy and enhance the production potential of traditional farming practice. Despite these advantages, there are gaps between results from experimental and field models, as well as many other factors (pesticide application, suitable design, assessment of relationship between rice, fish, soil, water, fertilisers); That need to be brought under control to improve the productive quality of each component of the system.

[Frei and Becker \(2005c\)](#) reported that the water needed for rice production ranges from approximately 8 000 to 12 000 m³ per hectare per crop, depending on the rate of water percolation and evapo-transpiration. For example, in developing countries, while all other cereal production averages 0.56 kg.m⁻³ of water, the water productivity for rice is evaluated at an average of 0.39 kg.m⁻³ of water ([Cai and Rosegrant, 2003](#)). The above observations prompt increasing the amount of food produced per unit of water to meet the demand for fresh water, rather than seeking new sources of water supply through construction of massive infrastructure ([Gleick, 2003](#)).

In this respect, countries with large areas of wetlands, mostly in Asia and in Egypt (Africa), intensified the production of rice, which is better indicated than any other crop in utilising water. For example, about 20 million ha out of 42 million ha of land under rice-cultivation was suitable for the adoption of rain-fed rice-fish integration systems in India ([Rao and Ram Singh, 1998](#)in [Mohanty *et al.*, 2004](#)). All the integrations above allow for the production of fish together with rice in the same field, where despite the diversification of produced food in the same amount of water, fish play a major role in weed and pest control in rice–fish culture ([Fernando and Halwart, 2000](#); [Mohanty *et al.*, 2009](#)).

Integrated fish farming in irrigation systems has been tried in Vietnam and in Thailand, re-using nutrient-rich wastewater mostly from catfish ponds but also from Nile tilapia ponds (integrated cage-cum-pond and pen-cum-pond culture system) (Yi *et al.*, 2003a), and to irrigate and fertilise rice crops (Yi *et al.*, 2006). As for fish cultured in rice fields, integrated fish farming and crop production via irrigation systems allow for addressing environmental problems which are likely to be caused by nutrient-rich effluent from fishponds. The nutrient richness of pond water is due to uneaten feed and fish faeces as the source of suspended solids and inorganic nutrients which often leads to the pollution of receiving waters. Fish production is always high, depending on the farming system applied in ponds and effluents help enhance crop production by up to 2.86–3.08 t.ha⁻¹ of rice (Yi *et al.*, 2006), and up to 63.8–66.7 t.ha⁻¹ of tomatoes (Ray *et al.*, 2010). In addition, the nutrient-rich effluent could completely substitute inorganic fertilisers (Yi *et al.*, 2006). Moreover, the integration of irrigation options helps lower the populations of disease vectors (both humans and domestic animals (Fernando and Halwart, 2000; Vromant *et al.*, 2002b; Frei and Becker, 2005c).

2.5.1 Fish yields, and fish species cultured in integrated rice-fish systems

Various species of fish are cultured in rice fields with trenches that serve as refuges for fish when water levels are lowered. The most commonly used species are common carp (*Cyprinus carpio* (Linnaeus 1758)); Nile tilapia (*Oreochromis niloticus*, Linnaeus 1758.); and silver barb (*Barbonymus gonionotus*, Bleeker 1850) (Frei and Becker, 2005c; Halwart and Gupta, 2010).

Apart from the common carp, in China, the most cultured fish species in rice fields are *Carassius carassius* (Linnaeus 1758); *Hypophthalmichthys molitrix* (Valenciennes 1844); *Aristichthys nobilis* (Richardson 1845); and *Ctenopharyngodon idella* (Valenciennes 1844) (Dashu and Jianguo, 1995; Cuo, 2001, in Frei and Becker, 2005c). *Catlacatla* (Hamilton 1822); *Cyrhinus mrigala* (Hamilton 1822); and *Labeo rohita* (Hamilton 1822) are commonly stocked in rice fields in India, while in other Asian countries, the rearing of Gourami (*Trichogaster pectoralis* Regan 1910), catfish (*Clarias macrocephalus*, Günther 1864), and snakehead (*Chana striata*, Bloch 1793) have been reported. In India and in Vietnam, rice culture is also integrated with prawn (*Macrobrachium rosenbergii* De Man 1879) production (Duong, 2001; Saha *et al.*, 2000, in Frei and Becker, 2005c). In Africa, integrated rice–fish culture has only been practiced successfully in Egypt, using mostly the Nile tilapia.

Fish stocking density in integrated rice-fish culture, may range from 2 000 to 35 000 individuals per hectare of juvenile fish of generally 25 g body weight for low density applications, while farmers introduce fingerlings of between 2 and 10 g for high stocking densities. Mohanty *et al.* (2009) presents rice-fish integrated culture as a system that accommodates fish farming carried out at four different intensities: traditional (capture); low intensity culture (without feed and fertilisers); medium density culture (only fertilisation); and high-density culture (with feed and fertilisation). In most countries, rice-fish integration is composed of intensive rice cultivation and extensive fish farming with very low fish yields (300 kg.ha⁻¹) (Nhan and Le Than Duong, 1997; Rothuis, 1998).

Data for fish yields in integrated systems vary between 200 and 700 kg.ha⁻¹ and are stocking-density dependant (Mohanty *et al.*, 2004). Considering various environments, fish species, stocking densities, inputs supplied, rice spacing and rearing purposes (whether for marketable

size or fingerlings), fish yields are found to have a wide range; from almost zero to 2250 kg.ha⁻¹ (Frei and Becker (2005b)).

2.5.2 Rice yield

Rice yields in integrated systems are typically in the range of 2 to 5 tonnes per ha; however, the yield vary according to the rice variety and the climatic conditions. Nonetheless, most literature reports show increasing rice yields in integrated systems compared to rice monoculture. For example, rice paddy yields range between 1.5 and 1.8 t.ha⁻¹.crop⁻¹ in rice alone, whereas it is 1.6 to 3.7 t.ha⁻¹.crop⁻¹ in integrated rice-fish systems (Haroon and Pittman, 1997). Regarding the rice and fish productivity in integrated systems in six Asian countries, Nile tilapia and common carp are the species constantly farmed in the six countries studied and the fish yields range from 0.8 to 1282 kg.ha⁻¹; this applies to the four species considered in this review (*O. niloticus*, *C. carpio*, *B. Gonionotus*, and *C. catla*) (Frei and Becker, 2005b; 2005c). Mohanty *et al.*, (2009), also showed that rice mono-cropping had significantly lower yields of rice, straw and number of panicles per m² when compared to rice–fish integration with or without selective harvesting. The percentage increase in rice grain yield in rice–fish systems, as opposed to rice mono-cropping was higher by about 25% and by 16.9%, with and without selective harvesting respectively. Contrarily, Yaro *et al.* (2005) found a marginal effect, but an increase, nonetheless, and reported a 4.6% increase in rice yield in rice–fish culture over rice monoculture.

2.5.3 Economic aspect

The overall production increase of the integrated system seems obvious, as the rice–fish system makes multiple use of the same single rice field and maximises the utilisation of land and water resources. Therefore, the integrated system has the potential to increase the net returns per unit farmed area. Ofori *et al.* (2005) reported a percentage increase ranging from 5 to 11%, while other researchers suggested that the addition of fish to rice paddies has no effect on rice yield (Rothuis *et al.*, 1998; Vromant *et al.*, 2002a). This is contrary to the findings of Mohanty *et al.* (2009), who observed a 23- to 35-fold increase in yield for rice mono-cropping and who reported

a 49% yield increase when applying the selective harvesting method, stating mono-cropping to be more beneficial than traditional rice–fish farming. In integrated aquaculture within irrigation systems, [Lala I.P.Ray \(2010\)](#) observed an increase of net benefit and reduced profitability value with increasing stocking density. Generally, the increased revenue over rice monoculture is higher than that reported in concurrent rice–fish systems, as fish has always a higher market value than rice in most countries.

The present study will characterise the change in net return, the return after variable cost, as well as the profitability of the different components of the integrated system. This is in order to assess the economic importance of the overall system, which combines the integrated rabbit–fish system and the integrated rice–fish system in a single design incorporating the irrigation aspect.

2.6 Summary

Various positive reasons prompt the rearing of rabbits in an integrated manner in general and with aquaculture in particular. Rabbits can be fed on low-cost material, consume small quantities of feed, can perfectly develop in inexpensive housing, are a means of utilizing small rural holdings with a high capacity to adapt under harsh climatic conditions. This makes rabbit-rearing a potentially successful alternative livestock enterprise and a family hobby for rural and urban families that contributes to food security and fights malnutrition. Rabbit droppings are an excellent source of fertiliser inputs to increase crop production when used for soil improvement and they similarly increase fish production when added to fishponds for the enhancement of water-nutrient levels. The only constraint that can lead to rabbit production failure is a brusque changing of environmental conditions, and a lack of high-quality management skills and commitment to providing rabbits with a secure, hygienic and healthy environment. The latter conditions can be easily provided through raising rabbits over fishponds.

Integrating rice and fish culture has shown the potential to optimise the benefits of scarce land and water resources through complementary use and it can, therefore, help countries keep pace with the ascending demand for food. Integrated rice–fish systems within irrigation systems are generally more beneficial than the rearing of fish in rice fields as separate units. The latter system

is typically composed of intensive rice cultivation and extensive fish farming with very low fish yields.

Integrated rabbit-fish and rice–fish systems are forms of Integrated Agriculture-Aquaculture systems (IAA) that are viable and ecologically sound ways of enhancing food security for resource-poor farmers. This prompts the optimisation of a system that combines the systems in a single design where the wastewater from the first serves as fertiliser input for the second. It is assumed that the combination would reduce the use of expensive feeds for fish, as well as rabbits, and prevent the application of inorganic fertilisers, as they could be completely substituted by nutrient-rich effluent. In Rwanda, where rabbits are reared in almost all rural households, rabbit farming appears to be a promising viable option which can undoubtedly contribute to reducing poverty and improving food security, even when it is carried out in a small-scale farming system.

3. CHAPTER THREE: Rearing rabbits over earthen fishponds in Rwanda: Effects on water and sediment quality, growth, and production of Nile tilapia (*Oreochromis niloticus* L).

The following articles are based on the chapter 3:

Rukera Tabaro S.*, Mutanga O., Rugege D., Micha, J-C., 2011 (*in press*). Rearing rabbits over earthen fishponds in Rwanda: Effects on water and sediment quality, growth and production of Nile tilapia *Oreochromis niloticus* L. *Journal of Applied Aquaculture*.

and

Rukera Tabaro S.*, Mutanga O., Rugege D., Micha J-C, 2011 (*in press*). Rabbit droppings, as an organic fertiliser in earthen ponds, to improve growth and production of Nile tilapia, *Oreochromis niloticus* L., in Rwanda. *Rwanda Journal /AJOL*

Abstract

Nine earthen ponds of 400 m² each, were stocked with 800 mixed sex Nile tilapia *Oreochromis niloticus* (LINNAEUS, 1758) fingerlings (14 g mean weight stocked at 2 fish.m⁻²) and fertilised with droppings voided by rabbits reared over fishponds and stocked at three different densities: (T1)=one, (T2)=two and (T4)=four rabbits per are (100 m²) of pond. After 140 days, results from this integrated rabbit-fish system showed: an increasing pattern in all nutrients in the three treatments except for nitrates which decreased with time in all treatments, and a good environment by physic-chemical parameters (Temperature, pH, dissolved Oxygen, and Secchi transparency). However, total nitrogen (TN) was low in ponds receiving dung from the highest stocking rate of rabbit (T4), but the difference between treatments was not significant (P<0.05). Fish mean weight at harvest, and fish yield were higher in ponds fertilised by the highest rabbit stocking rate: 42.32 g and 6.35±1.0 kg/are respectively (1 are = 100 m²), than in other ponds. This study showed that a larger amount of rabbit is better for the quality of water for *Nile tilapia* and its production. Further studies to optimise rabbit density on fishponds are needed.

Keywords: Rabbit survival, water quality, pond soil quality, fish production.

3.1 Introduction

Rwanda is a country with a high population density (>300 inhabitant/km²) and a high rate of population growth (3.0%) which exceeds the increase rate of agriculture (2.2%) (MINECOFIN, 2002). Even though Rwandan agriculture employ over 90% of the Rwandan labour force, the food and nutritional needs of the population, which is still characterised by a high level of malnutrition, are not met. Nor is agriculture able to contribute substantial income to the economy of the country (MINECOFIN, 2003). Rwanda has ranked, by importance, six broad identified areas on which it will act on a priority basis: rural development and agricultural transformation have been identified as the most important (MINECOFIN, 2002). Strategies for the agricultural sector include increasing rural incomes, enhancing food security, and transforming agriculture by moving from subsistence to market-based activities. The aim of this study is to contribute to these goals by optimising an integrated agro-ecosystem which seeks to contribute substantially to Rwandans' nutritional needs while increasing income. The envisaged system is made of two fully integrated levels of production: the rabbit–fish integrated system.

Fish production in Rwanda's ponds is dominated by Nile tilapia (*Oreochromis niloticus* Linnaeus 1758) monoculture and in polyculture with African catfish (*Clarias gariepinus*, Burchell 1822), where catfish fingerlings are available. Fish farming is undertaken in individual and co-operative fishponds that are sometimes integrated with crop production and to a lesser extent with livestock production. Ponds are fed occasionally and fertilised using different types of grass compost cut from the pond dikes and very small amounts of animal manure produced on hills near homesteads where animals are kept (Micha, 2001).

Rabbit–fish integration

Integrated rabbit–fish farming works on the principle that fertilised water develops a marked quantity of phytoplankton and zooplankton, the natural feed of one of the main fish species produced in aquaculture, the Nile tilapia. Rabbit faeces and urine, as well as other livestock wastes, are potential sources of environmental pollution if they are just thrown in the environment but when dumped into pond water, they decay and release important nutrients; a source of phytoplankton development. Inversely, their use as water fertiliser compares well with

the Integrated Agriculture–Aquaculture (IAA) system that is capable of predicting fish growth and production, stimulating crop biomass growth, stimulating soil organic matter and nitrogen concentrations based on waste recycling processes (Jamu and Piedrahita, 2002). Rabbits are herbivorous animals consuming high roughage, offering limited competition to humans and other domestic animals for similar foods. Rabbits utilise fibrous by-products that are not commonly used for poultry or pigs. The main importance of rabbit farming is in the continuous supply of rabbit meat using natural, inexpensive, and renewable on-farm resources produced from an integrated enterprise that benefits both the farm family and the community in providing nutritious meat as well as income (Lukefahr, 2008). Cheek (1986), cited by Lukefahr (2008), reported that the on-farm resources (by-products of grain, crops, and animals) are used as supplement feed together with legume forage which is considered typically to be the most important source of protein for rabbits. For all these reasons, rabbits are considered the best animals for a sustainable small-scale production activity that is recommended for lesser developed countries.

Furthermore, rabbit excrement contains not only several nutrients but also acts as a source of digestible energy. Rabbit manure is a rich source of inorganic nitrogen and phosphorus (Franco, 1991; Kumar and Ayyapan, 1998) that are important for aquaculture, as they are readily utilised by phytoplankton growth. McCroskey (2001) reported that rabbit droppings have about 3–1.5–0.3 of N–P–K and, according to Lebas *et al.* (1996), rabbit manure is much richer in nutrients than ordinary farm manure that mostly contains 0.4–0.6 % nitrogen, while rabbit dung is composed of up to 2.4% (Table 3.1).

Preliminary results obtained from rabbit–fish integration (Franco, 1991; Breine *et al.*, 1996) report that rabbit dung application in ponds increases phytoplankton abundance, indicating that it has a notable impact on primary production. During his study on the effect of rabbit dung on the growth of Nile tilapia, Breine *et al.* (1996) observed a fish growth rate that was 5.1 times that of the control group (tanks with water only). Moreover, domestic rabbits have the adaptability to exist on a wide and varied diet, in conditions ranging from tropical to arctic although research has shown that climate can affect rabbit performance (Fayez *et al.*, 1994; Yamani and Farghally, 1994; Lebas *et al.*, 1996).

Table 3.1: Approximate N, P, and K values of animal manure

Animal	Nitrogen %	Phosphoric acid %	Potash %
Dairy cow	0.57	0.23	0.62
Beef steer	0.73	0.48	0.55
Horse	0.7	0.25	0.77
Swine	0.49	0.34	0.47
Sheep/goat	1.44	0.5	1.21
Chicken	1	0.8	0.39
Rabbit	2.4	1.4	0.6

Source: Lebas *et al.* (1996)

In Rwanda, especially in rural areas, rabbit husbandry is a common and easy activity for almost all livelihoods. Smallholder farmers who cannot afford the farming of big livestock have become particularly interested in rabbit farming for both profit and subsistence, mainly due to the high fecundity of the rabbit and its short production cycle, associated with low investment and production costs. Research on integrated rabbit–aquaculture is, however, very limited, mainly because climatic conditions required for rabbits do not match those for aquaculture in a natural environment. Preliminary results obtained in Cameroon pointed out the promising effect of rabbit manure as a water fertiliser for Nile tilapia ponds and as food for catfish (*Heterobranchus longifilis* Valenciennes, 1840) (Breine *et al.*, 1995).

Franco (1991), using dried rabbit dung to feed Nile tilapia in mesocosms, reported that fish did not eat faecal pellets of the adult rabbits but did consume faecal pellets voided by weanling and kid rabbits, which tempts one to suggest that Nile tilapia could be attracted by the milk residuals and derivatives found in pellets voided by young rabbits. The direct integration of rabbit–fish (rearing rabbit over fishponds) was tried for the first time in Rwanda in 1988 by researchers in the National Fish Culture Service (SPN) at Kigembe (Southern province). Van Vleet (1997) reported similar fish yield (6000 kg.ha⁻¹) to those obtained from integration fish–chicken (6500 kg.ha⁻¹) and even better than yields from integration with pigs (5000 kg.ha⁻¹) and ducks (4500 kg.ha⁻¹) on the same fish farm. A load rate of 60 rabbits per fishpond of four are surface (400 m²), recommended, although observation on the impact of rabbits on the quality of water over the rearing time were not considered. Rabbit dung has also been used successfully in integrated

aquaculture and biogas production. Biodigested effluent, after rabbit dung decomposition, has been used as organic fertiliser in fishponds from which [Mahadevaswamy and Venkataraman \(1988\)](#) reported good yields (8.9 kg/100m³/120 days), favourable colour, flavour and taste for the common carp (*Cyprinus carpio*) and major carp (*Labeo rohita*).

This study is the start of part of a broad research programme to investigate the potential of the integration of agriculture and aquaculture that includes rabbits while protecting the environment in Rwanda. It focuses on the effects of rabbit droppings on fishpond water and pond sediment quality and consequently on the growth and production of filter feeder fish, the Nile tilapia.

3.2 Materials and Methods

3.2.1 Overall research methodological approach

The overall objective of this research was to develop a well integrated agriculture–aquaculture system, starting with farming on dikes to get food that was likely to feed rabbits and fish as well as humans. The rabbit droppings directly fertilised the water to boost plankton production that is appropriate natural feed for filter fish like Nile tilapia. Enriched pond water was then used to fertilise the rice field, using a trough irrigation technique (Figure 3.1) rather than being discharged into the environment, thus causing pollution. It was hoped that the outcome of this system will improve the quality of food supply and contribute to reducing poverty and improve the livelihoods of Rwandan rural poor farmers.

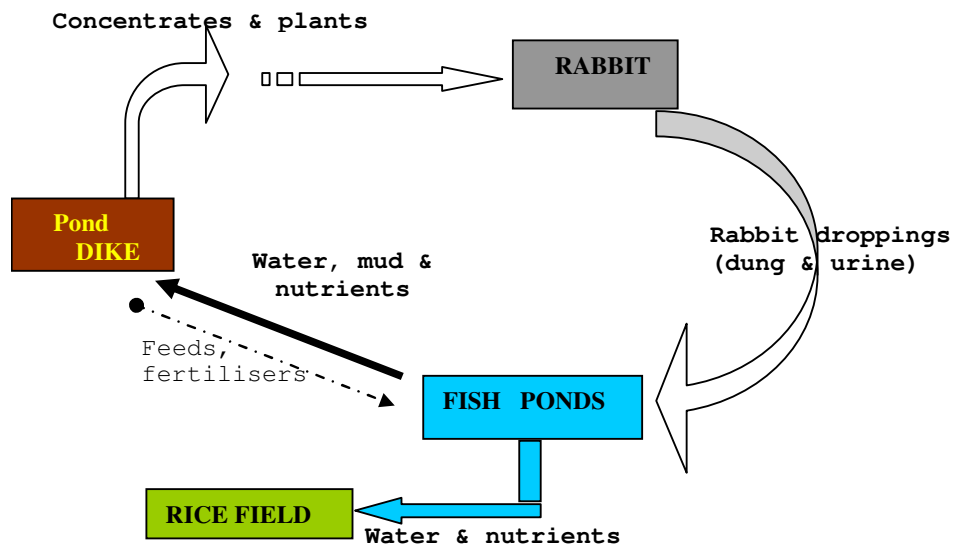


Figure 3.1: A diagram of the ecological model of a complex IAA system: the integrated rabbit–fish–rice system (IRFR system) implemented in the SPIR-NUR for the optimisation of functioning of this complex integration.

3.2.2 Study site profile and overall experimental arrangement

The study was carried out in five phases, including documentary research conducted at the University of Kwazulu-Natal Life Sciences Library, the National University of Rwanda (NUR), as well as the internet, and experiments that were conducted at the Rwasave Fish Farming and Research Station (SPIR–NUR) in Rwanda.

The SPIR-NUR is a fish farming and research station, belonging to the National University of Rwanda, which is composed of 103 fish ponds of various sizes from 0.02–0.42 ha, covering 8.5 ha area, and built on a total area of 18.5 ha. Experimental rice fields were built for the purpose of the current study and were at a lower level than the experimental ponds in order to allow irrigation by gravity (Figure 3.2).

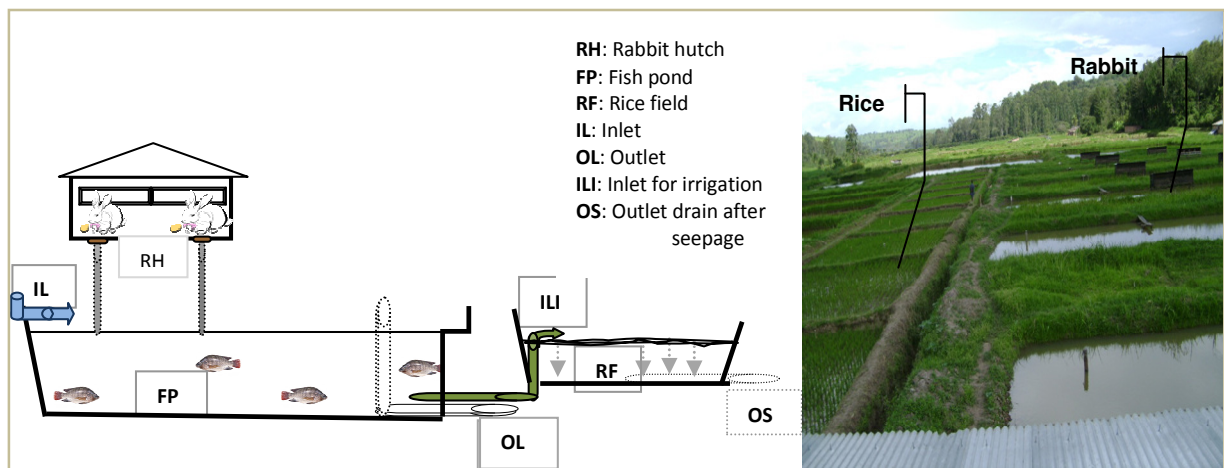


Figure 3.2: A profile (photograph and diagramme) of the rabbit–fish–rice integrated system that constituted the experimental study conducted at the Rwasave Fish Culture Research Station. Note the connectivity between the rabbit hutch, the fishpond and the rice field. The pond is here drawn lengthwise.

Rwasave is located in the Huye district, at approximately 2 km from Butare city, in the Southern province of Rwanda, and at about 130 km south of the capital city of Kigali (Figure 3.3). The Rwasave research station lies at 2°40'S and 29°45'E of latitude and longitude and 1625 m elevation, its weather is characterised by four seasons as like the whole Rwanda.

During this study, water temperature at dawn averaged 13 – 20°C while afternoon temperatures reached 30°C in the supply canal and between 20.2 and 26.35°C in fish ponds, morning and afternoon temperatures, respectively. Rwasave mean annual rainfall is known to average 1200 mm, with relative air humidity from 59% in July to 83% in April (McElwee, 1999), but the rainfall averaged 940 mm during the current study. In fact, the weather for the whole of Rwanda is characterised by four identifiable seasons: a long dry season (mid-June to mid-September); a short rainy season (mid-September to mid-December); a short dry season (mid-December to mid-February); and a long rainy season (mid-February to mid-June).

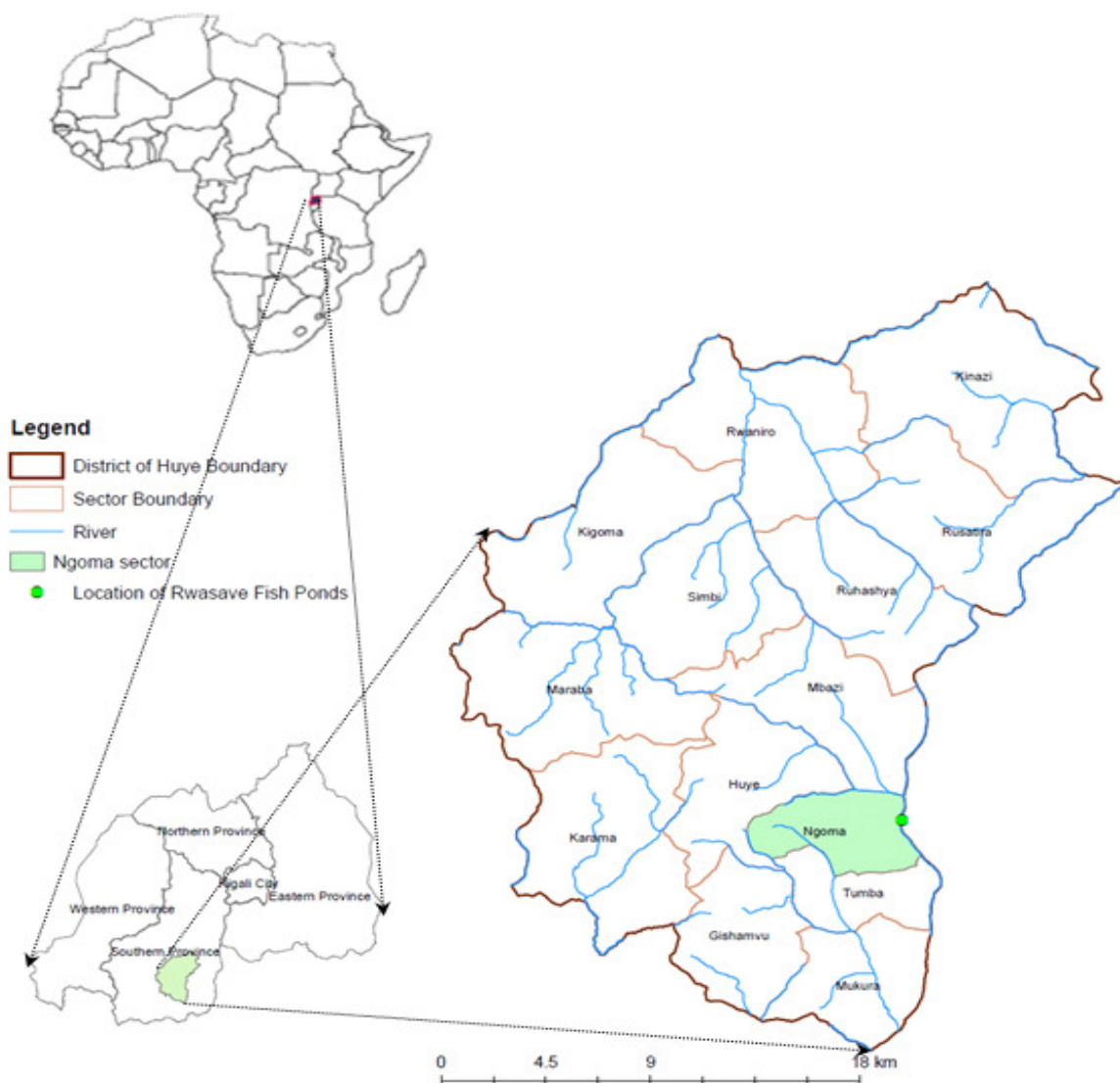


Figure 3.3: Maps showing the location of the research site (Rwasave Fish Farming and Research Station) in the Ngoma sector, Huye district and in Rwanda, a small country in the central east of Africa.

This chapter focuses on the impact of rabbit droppings on the fishpond water quality, the primary production in ponds and consequently Nile tilapia growth and production as well as the capacity of rabbits to adapt in wetland conditions.

The experiment on which the present chapter is based was conducted between March 20th and August 19th, 2008, in nine earthen ponds (size: 400 m², maximum water depth: 110 cm) at the SPIR-NUR. Rabbits were reared in hutches suspended over fishponds that had first been drained, dredged, dried, and then refilled with water from an open supply canal (Figure 3.2). After the initial filling water was only added to compensate for losses from evaporation and seepage.

Three treatments were assigned randomly in triplicate ponds fertilised with rabbit droppings falling directly from 100, 200, and 400 rabbits per hectare of pond, being treatments T1, T2, and T4. Rabbits were fed *ad libitum* grass cut on the levees of nearby ponds and received water *ad libitum* as well. At the same time, each pond was stocked with 800 fingerlings of mixed sex Nile tilapia (average weight: 14.9 g) at a density of 2 fish per m². No supplementary feed was given to the fish during the experiment.

3.2.3 Physico-chemistry of fish pond water

Water transparency (Secchi disk visibility), temperature, dissolved oxygen (WTW oxi 325/set), pH (WTW pH320/set 2), and electrical conductivity (WTW LF 38/set) were measured every two weeks at 07h00 directly in ponds in both surface about 10cm depth) and bottom (about 85cm depth) layers. At the same time, water samples were collected at depths of between 70 and 100 cm in the middle of each pond using a Van Doorn water sampler, were mixed and kept at 4 °C until analysis of nutrient composition in the laboratory. Ammonia nitrogen analysis was made using the titrimetric method after distillation (Descy, 1989), nitrates were analysed by the spectrophotometric method after digestion with phenoldisulfonic acid (Boyd, 1979), nitrites were analysed using Standard Methods (APHA, 1985). Total nitrogen was analysed by the Kjeldahl method (Léonard and Kanangire, 1998). Orthophosphates (soluble reactive phosphorus) were analysed by the ascorbic acid method of Golterman *et al.* (1978), adapted by Descy (1989), while total phosphorus was determined by persulfate digestion (Léonard and Kanangire, 1998). Total alkalinity was determined using the titrimetric method (Descy, 1989).

3.2.4 Primary production in fish ponds

Fishpond primary productivity was determined through measurement of dissolved oxygen, using an oxymeter (WTW oxi 325/set). Oxygen concentrations were measured at different depths; produced oxygen, as well as consumed oxygen by respiration, were recorded after incubation of light and dark bottles to finally calculate the net and gross productions. Daily productivity was determined using a photosynthesis simulator computer program, PSS 2000 version 2.1 (Dauta and Capblancq, 1999).

3.2.5 Pond bottom soil chemistry

Pond bottom soil or sediment was assessed according to its nutrient content following the introduction of rabbit waste that was constantly dropped in ponds and assumed to have settled in sediment. A sediment sample, composed of a mixture of eight clumps of earth was taken using a drill along an “S” trajectory on the pond base.

The total nitrogen (organic form) in sediment was determined by the Kjeldahl method presented in PAGES *et al.*, (1982), adapted by Léonard and Kanangire (1998) and in (APHA, 1985). Total phosphorus in pond sediment was measured after soil sample extraction using hydrochloric and nitric acids after incinerating sediment samples in an oven at 600°C for three hours (IITA, 1975, adapted by Léonard and Kanangire, 1998) and the available phosphorus (Orthophosphates) was determined through the BRAY method presented in PAGES *et al.* (1982) and adapted by Léonard and Kanangire (1998).

3.2.6 Fish growth and production

Thirty five fish per pond were sampled randomly every two weeks over 127 days. Individual fish biomass was measured using an electronic balance (Mettler balance, accuracy: 0.1g). Each time fish were returned to the corresponding ponds. One hundred and twenty seven days after stocking, the ponds were completely drained; fish were harvested, counted and weighed to the nearest gram. Fish data at stocking and harvest were used to calculate the survival rate: $SR (\%) = 100 - [100 \cdot (N1-N2) / N1]$; the specific growth rate $SGR (\% \cdot \text{day}^{-1}) = 100 \cdot ((\ln W2 - \ln W1) / d2 -$

d1); the daily weight gain DWG (g.day^{-1}) = $(W_2 - W_1) / (d_2 - d_1)$ where N_1 and N_2 are the number of fish at stocking and harvest time respectively. W_1 and W_2 are fish biomass at stocking and harvest time respectively, and d_2 and d_1 are the day for fish harvest and fish stocking day respectively (the rearing time in days). The net production ($\text{kg.are}^{-1}.\text{yr}^{-1}$) as well as the yield (kg.are^{-1}) were also calculated (1are = 100m²).

3.2.7 Statistical analysis

All collected data was analysed using GENSTAT *Discovery Edition 3* software.

For water quality parameters, including primary productivity in the experiment, analysis of variance (ANOVA) for repeated measures was used. The validity of data was checked with the least significant difference of means (LSD) and was used to check significances at 5% level. One-way ANOVA was used for the fish growth parameters like SGR, DWG, productivity and yield, rabbit biomass, and survival rate (SR), as well as for pond mud quality.

3.3 Results

3.3.1 Rabbit growth and survival

The rabbit average body weight increased significantly in all treatments, moving from about 500 to almost 2000 g. However, treatment T1 with 1 rabbit per one square meter hutch showed significant higher weight gain than T2 and T4 which were not significantly different from each other (Table 3.2 and Figures 3.4).

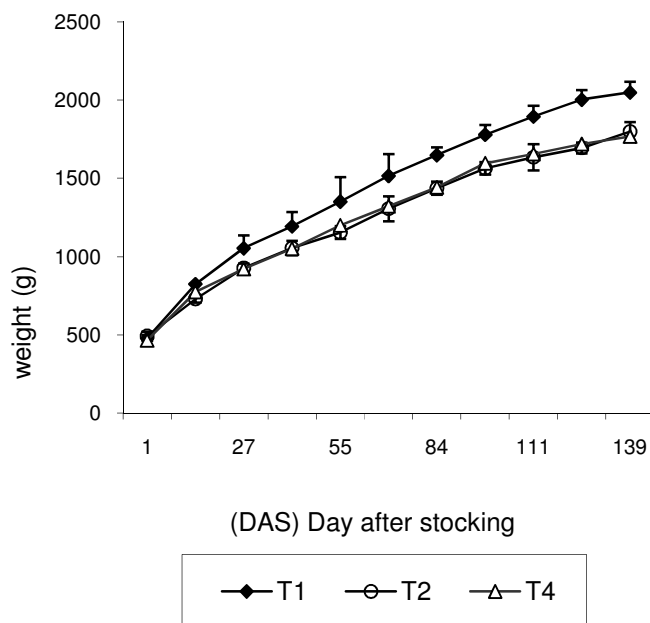


Figure 3.4: Change of the rabbit body weight illustrating the weight gain, when reared over fish ponds for 140 days at 1, 2, and 4 rabbits per square metre hutch.

The average daily weight gain (DWG) ($\text{g}\cdot\text{day}^{-1}$) and the specific growth rate (SGR $\%\cdot\text{day}^{-1}$) were different between treatments (Table 3.2). Rabbits in T1 gained $11.4\text{g}\cdot\text{day}^{-1}$ while rabbits in T2 and T4 gained an average of $9\text{g}\cdot\text{day}^{-1}$. Likewise, T1 was characterised by a SGR significantly higher than those for T2 and T4, which treatments were not statistically different.

Table 3.2: Mean weight (g), Specific Growth Rate (SGR $\% \cdot \text{day}^{-1}$), Daily Weight Gain (DWG $\text{g} \cdot \text{day}^{-1}$), and Survival Rate (SR %) of rabbits reared over fish ponds in Rwasave wetland (south Rwanda) for 140 days

Treatments	Mean weight (g)	SGR ($\% \cdot \text{day}^{-1}$)	DWG ($\text{g} \cdot \text{day}^{-1}$)	SR (%)
T1	2049.6 \pm 67.83 ^a	1.05 \pm 0.03 ^a	11.4 \pm 0.42 ^a	100 \pm 0.00
T2	1799.2 \pm 60.46 ^b	0.94 \pm 0.05 ^b	9.5 \pm 0.46 ^b	95.8 \pm 7.21
T4	1767.7 \pm 16.48 ^b	1.0 \pm 0.03 ^b	9.4 \pm 0.22 ^c	95.8 \pm 7.22
LSD (5% level)	80.33**	0.081*	0.038**	NS P = 0.45

Numbers with the same superscript letter are not significantly different at 5% level of probability); *= significant difference, ** = significant difference up to 1% level probability; NS = non-significant differences. LSD = Least Significant Difference between mean.

3.3.2 Effects of rabbit dung on the quality of fish pond water

3.3.2.1 Physico-chemical parameters

Important biogenic parameters that were of interest in this study were nitrogen and phosphorus forms as they influence pond primary production and consequently the filter fish feeders like Nile tilapia. The dynamics of a fishpond lie in the variation of not only nutrient (biogenic elements) concentration but also physico-chemical parameters (temperature, dissolved oxygen, pH and salinity). In general, and for each treatment, the trend of the parameter variation was drawn using data collected either every two weeks, or twice (start and end of experiment) or three times (beginning, middle, and end of experiment). Table 3.3 shows the general mean values of physico-chemical parameters daily measured, twice or three times per day, as well as minimum and maximum mean calculated on replications for each treatment. Overall, the highest temperature, pH, and conductivity were observed in the treatment with four rabbits per are of pond (T4) as the source of fertilisation. These ponds had lower values, but not significantly, on dissolved oxygen, primary production, and water transparency.

Table 3.3: Means and standard errors for physico-chemical parameters of water obtained from three different rabbit stocking rates (100, 200, 400 rabbits per hectare). Values are average of either surface and bottom layers or three daytime measurements for both surface and bottom layers

Parameter	Treatments		
	T1	T2	T4
Temperature (°C)	22.0 ± 0.20 (20.09 – 24.42)	22.0 ± 0.20 (20.06 – 24.86)	22.0 ± 0.19 (20.2 – 25.26)
pH	6.9 ± 0.19 (5.57 - 8.81)	6.5 ± 0.22 (5.0 – 8.87)	6.7 ± 0.26 (5.55 – 9.08)
Conductivity (µS.cm ⁻¹)	115.6 ± 1.48 (104.83 – 128.0)	120.5 ± 0.65 (110.75 – 132.50)	137.9 ± 3.37 (111.80 - 155.67)
Dissolved Oxygen (mg.l ⁻¹)	5.0 ± 0.38 (1.67 – 8.91)	4.7 ± 0.43 (1.59 – 8.17)	4.9 ± 0.60 (1.41 – 10.48)
Primary productivity (mgC.m ⁻² .day ⁻¹)	296.9 ± 25.8 (178.01 – 353.22)	321.8 ± 29.2 (238.59 – 426.82)	292.6 ± 22.6 (243.55 – 389.05)
Secchi disk visibility (m)	0.4 ± 0.01 (0.33 – 0.45)	0.4 ± 0.01 (0.32 – 0.41)	0.3 ± 0.01 (0.23 – 0.43)

All data are means ± standard error of mean of the data collected during the entire period of experiment. Data in parentheses represent the minimum and the maximum observed within each treatment (average on 3 replicates).

a. Temperature

For all treatments (Figure 3.5), temperature was lower during the dry season (19.6–24.4 °C in June, July) and higher during the rainy season (20.6–27.8 °C in March, April, and May). The bottom layer always had lower temperatures than the surface, whatever the time during the day.

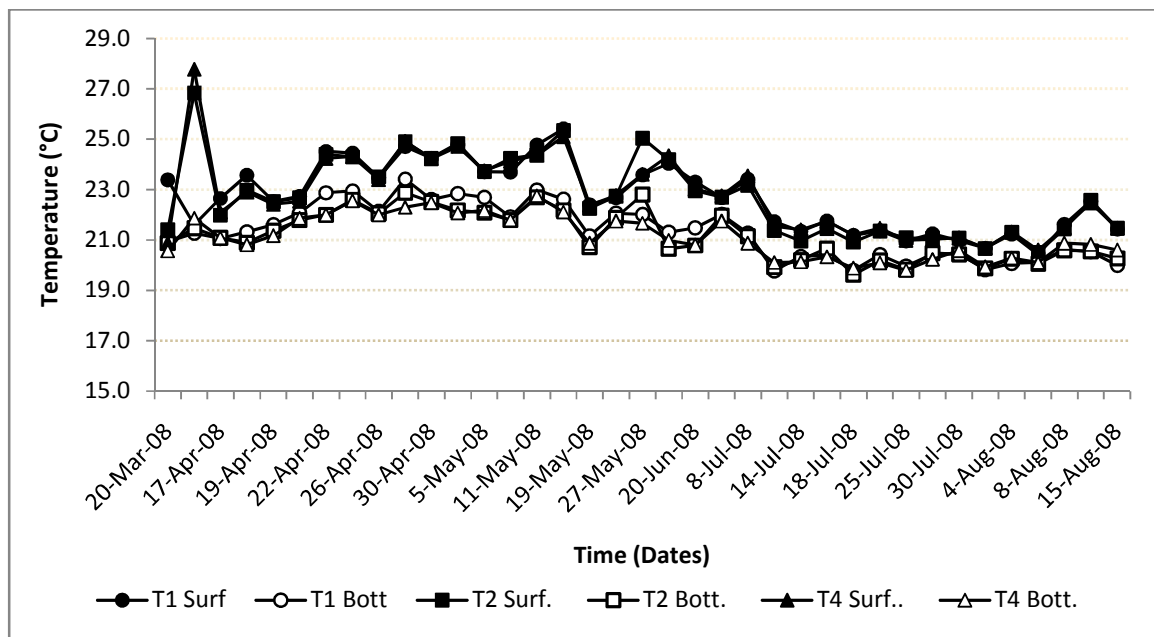


Figure 3.5: Temperature variation in integrated rabbit–fish production during experiments with three different rabbit densities on ponds (T1: 100, T2: 200, and T4: 400 rabbits per hectare of pond). (Surface temperature in shaded curve and bottom temperature in unshaded curve).

a. Dissolved oxygen (DO)

Concentrations for dissolved oxygen in water were in the vicinity of 5.0 mg.l^{-1} and reached a maximum of 10.4 mg.l^{-1} during the day in T4. Mean minimum concentrations of DO were measured in the morning hours and ranged between 1.41 and 1.67 mg.l^{-1} . A significant decrease in morning dissolved oxygen was observed in all treatments, but mostly in T4 (Figure 3.6) as time passed. Bottom pond oxygen remained lower than surface levels of dissolved oxygen during the experiment time.

Similar trends were observed for parameters affected by the dynamics of organic matter in ponds, such as the remarkable decrease that was observed in water transparency (secchi disk visibility) (Figure 3.7) and pond primary productivity (Figure 3.8), where again T4 receiving much more manure showed lower values in the indicated parameters.

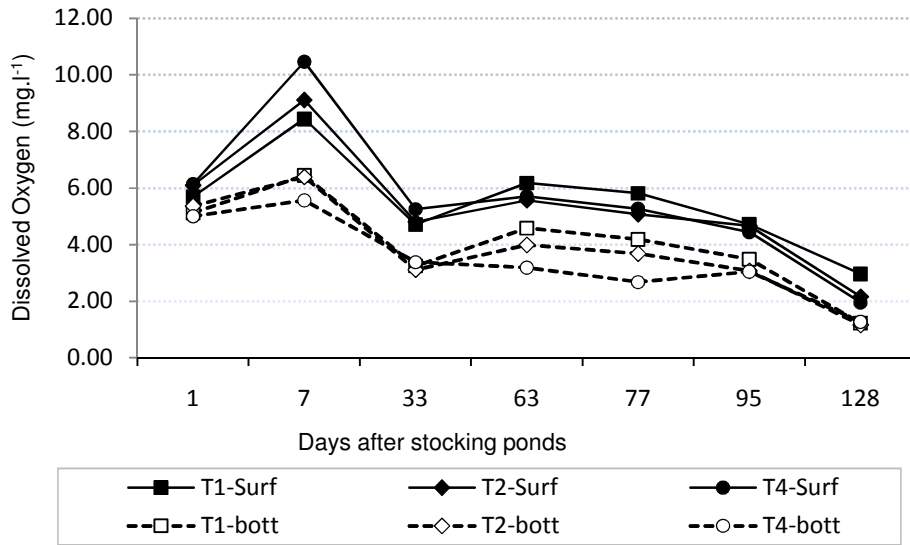


Figure 3.6: Trends in oxygen variation during rearing time at three different rabbit densities on ponds (T1: 100, T2: 200, and T4: 400 rabbits per hectare of pond). Each value is an average of 3 oxygen concentrations from replicates for surface (continued line) and for bottom (discontinued line) layers.

b. Water transparency

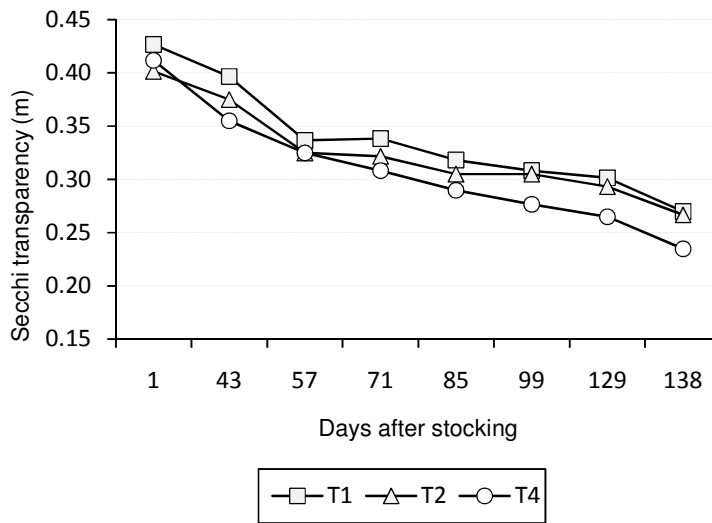


Figure 3.7: Water transparency (m) variation during five months of rearing rabbits over fish ponds at three different rabbit densities on ponds (100, 200, and 400 rabbits per hectare). X axis represents days after stocking rabbit hutches with 100, 200 and 400 rabbits respectively T1, T2, and T4.

Primary productivity for fishponds fertilised by rabbit droppings

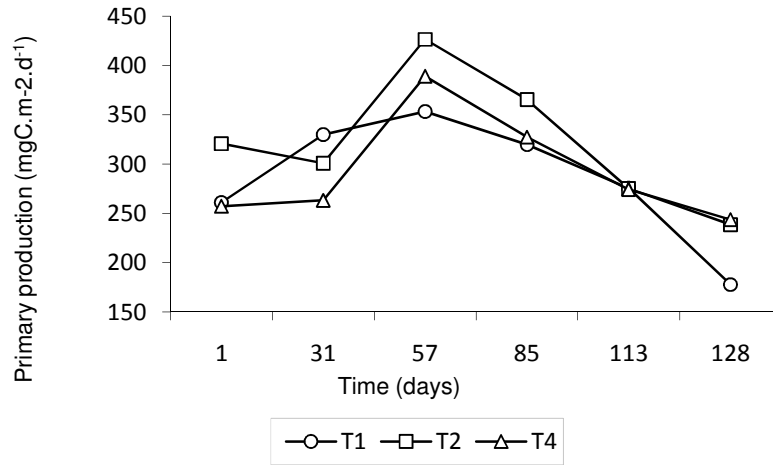


Figure 3.8: Trend of the primary productivity change in fish ponds fertilised by rabbit droppings falling from above ponds at three different rabbit densities (T1, T2, and T4 that is 100, 200 and 400 rabbits per hectare of pond respectively).

c. pH

In general, the pH measured in water varied from 5 to 9.08. Obtained daytime mean values showed that pH increased and midday and afternoon pH values were significantly higher ($P < 0.05$) than the morning ones (Figure 3.6).

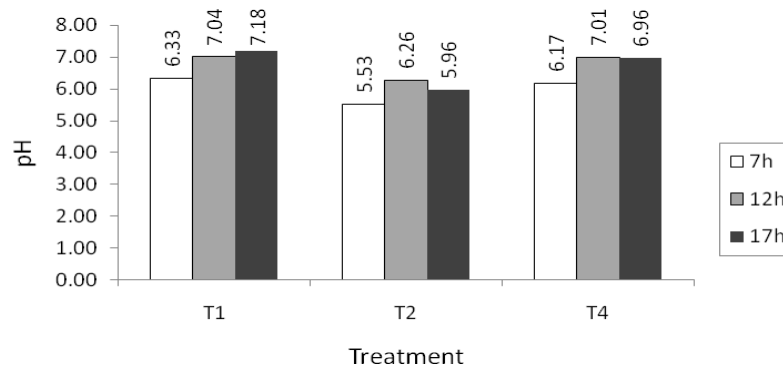


Figure 3.9: Daytime pH variation within ponds at three different rabbit densities on ponds. Each value is an average pH of three values being replicates and a mean value on data from pH biweekly measured for nearly 5 months.

d. Alkalinity

Total alkalinity ($\text{mg.l}^{-1} \text{CaCO}_3$) in the pond water did not differ significantly between treatments. Slightly higher values were observed in ponds receiving droppings from a bigger number of rabbits, T4, except at the end of the experiment where the reverse situation was observed but no detectable differences could be seen between treatments. Mean values lay between 43.33 and 72.67 mg.l^{-1} , showing a trend of increasing alkalinity over time seen mostly in T4.

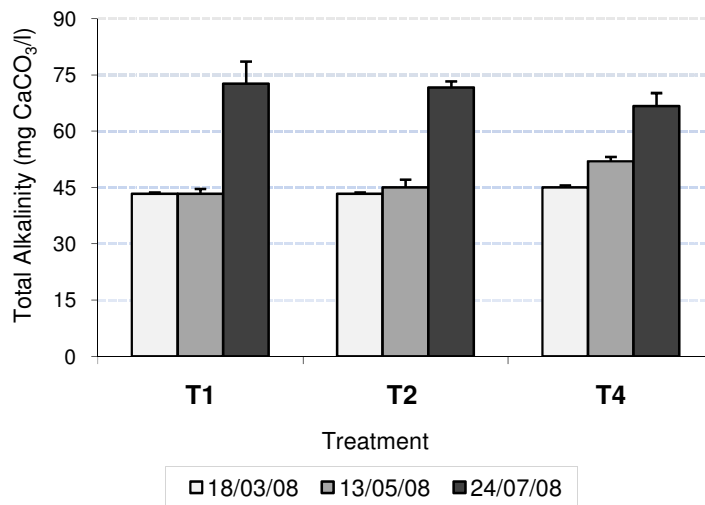


Figure 3.10: Changes in total alkalinity ($\text{mg.l}^{-1} \text{CaCO}_3$) of fish pond water fertilised with three different rabbit densities on ponds during nearly five months rearing.

e. Electrical conductivity

At the beginning of the experiment water conductivity values lay between 105 and 122 $\mu\text{S/cm}$ at 25°C in the three treatments. Three months later, there was a significant increase of conductivity in the treatment where there was the most rabbit dung from the highest rabbit stocking rate (T4) and the same trend was maintained until the end of experiment. The conductivity of water in T1 and T2 did not differ significantly during the nearly five months of rearing rabbits over fishponds (Figure 3.11). Water electrical conductivity in T4 ($158 \pm 2.5 \mu\text{S/cm}$) was significantly higher than in T1 ($128.7 \pm 1.1 \mu\text{S/cm}$) and in T2 ($132.5 \pm 0.6 \mu\text{S/cm}$).

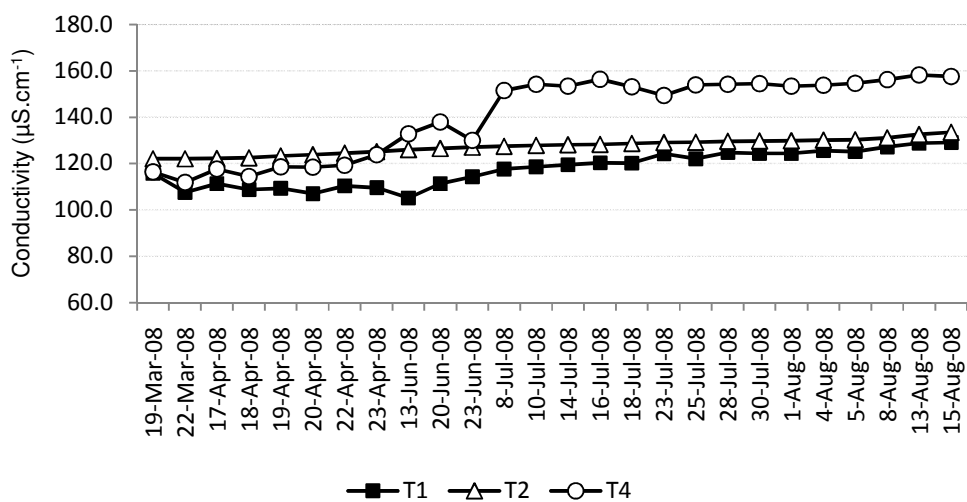


Figure 3.11: Changes in water electrical conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$ at 25°C) in rabbit–fish integrated farming (T1: 100 rabbits.hectare⁻¹, T2: 200 rabbits.hectare⁻¹, T4: 400 rabbits.hectare⁻¹ of pond). Each value is an average of 3 replicates and 2 layers in pond (surface and bottom).

3.3.2.2 Nutrients

Assessed nutrients of nitrogen forms in fishpond water were ammonium ($\text{NH}_4\text{-N}$), nitrites ($\text{NO}_2\text{-N}$), nitrates ($\text{NO}_3\text{-N}$), and total nitrogen (TN). Similar trends of significant increase were shown by all these nitrogen nutrient forms except nitrates that increased during the first month (Figure 3.9 C) of the experiment and decreased during the rest of experiment time.

Ammonia (Figure 3.12A and Table 3.4) increased with time in all treatments which showed statistical differences between them. Treatment where there were droppings from the highest rabbit stocking rate (T4) had a significantly higher ($P < 0.001$) ammonia concentration than T2 and T1 treatments for which ammonia concentrations were not significantly different ($P > 0.05$). Mean ammonia concentrations, in ensemble, were between $0.33 \pm 0.2 \text{ mg}\cdot\text{l}^{-1}$ and $1.07 \pm 0.05 \text{ mg/l}$ obtained in T4 at the end of experiment. The increase in time of ammonia concentration showed that T4 was significantly higher ($P < 0.001$).

Concentration in **Nitrites** (Figure 3.12B) and ammonia are the nitrogen forms that can escalate up to toxic levels due to accumulation in organic matter in fishponds (Losordo, 1997).

Nitrites were significantly higher ($P<0.001$) in ponds treated with 4 rabbits per are (100 m^2). Mean nitrite concentrations were $0.70\pm 0.10 \text{ mg.l}^{-1}$ in T4, while concentrations were $0.40\pm 0.09 \text{ mg/l}$ and $0.50\pm 0.12 \text{ mg.l}^{-1}$ in T1 and T2, respectively (Table 3.4).

Total nitrogen (TN) concentration in fishpond water had the same pattern as nitrites and ammonia nitrogen relative to rearing time ($P<0.001$), but treatments did not differ among them (Figure 3.12D). It was observed that TN concentration increased in direct relation with manuring time.

Table 3.4: Average concentrations of r nutrients in water obtained from three different rabbit stocking rates (T1: 100 rabbits.hectare⁻¹, T2: 200 rabbits.hectare⁻¹, T4: 400 rabbits.hectare⁻¹ of pond.. Samples were a mixture of water from the surface and bottom layers of the pond

Nutrients	Treatments		
	T1	T2	T4
1. Ammonia-nitrogen (mg.l^{-1})	0.4 ± 0.02 ^a	0.5 ± 0.18 ^a	0.7 ± 0.24 ^b **
2. Nitrites-nitrogen (mg.l^{-1})	0.4 ± 0.05 ^a	0.5 ± 0.07 ^a	0.69 ± 0.41 ^b **
3. Nitrates-nitrogen (mg.l^{-1})	0.7 ± 0.29 ^a	1.5 ± 0.25 ^a	2.72 ± 0.41 ^b **
4. Total nitrogen (mg.l^{-1})	13.5 ± 0.23 ^a	13.2 ± 0.88 ^a	12.45 ± 0.53 ^a ns
5. Total phosphorus (mg.l^{-1})	0.6 ± 0.06 ^a	0.7 ± 0.07 ^a	0.94 ± 0.06 ^b *
6. Soluble reactive phosphorus (mg.l^{-1})	0.1 ± 0.01 ^a	0.1 ± 0.01 ^a	0.21 ± 0.04 ^b **

All data are means \pm standard error of mean from data collected on 3 replicates during the entire period of experiment. Data that have same superscripts letters in the same row are not significantly different (ns). (*) different at $P<0.05$, and (**) different at $P<0.01$.

Contrary to other nitrogen forms, **Nitrate** concentration decreased over time showing high values in midterm of the experiment (Figure 3.12C) especially in T2 and T4. Nitrate concentration values were 0.75 ± 0.51 , 1.46 ± 0.43 , and $2.72\pm 0.60 \text{ mg.l}^{-1}$ respectively for T1, T2, and T4. Treatment T4 had significantly higher concentrations of nitrates-nitrogen ($P<0.001$), while no statistical difference was evident between T1 and T2 concentrations (Table 3.4).

Phosphorus nutrients were analysed into water sample in 2 forms: total phosphorus (TP) and soluble reactive phosphorus (SRP) or orthophosphate. During the current study, the forms of phosphorus showed similar trends; they increased significantly over time ($P<0.001$) in all treatments, but the treatment with the most number of rabbits on ponds (T4) showed significantly high concentrations of SRP ($P<0.01$) and significant concentrations of TP ($P<0.05$). Mean TP concentration values were 0.62 ± 0.11 , 0.69 ± 0.12 , and 0.94 ± 0.10 mg.l^{-1} respectively in T1, T2, and T4, while values of 0.07 ± 0.02 , 0.10 ± 0.02 , and 0.21 ± 0.07 mg.l^{-1} of SRP respectively in T1, T2, and T4 treatments (Figure 3.12E&F) were observed.

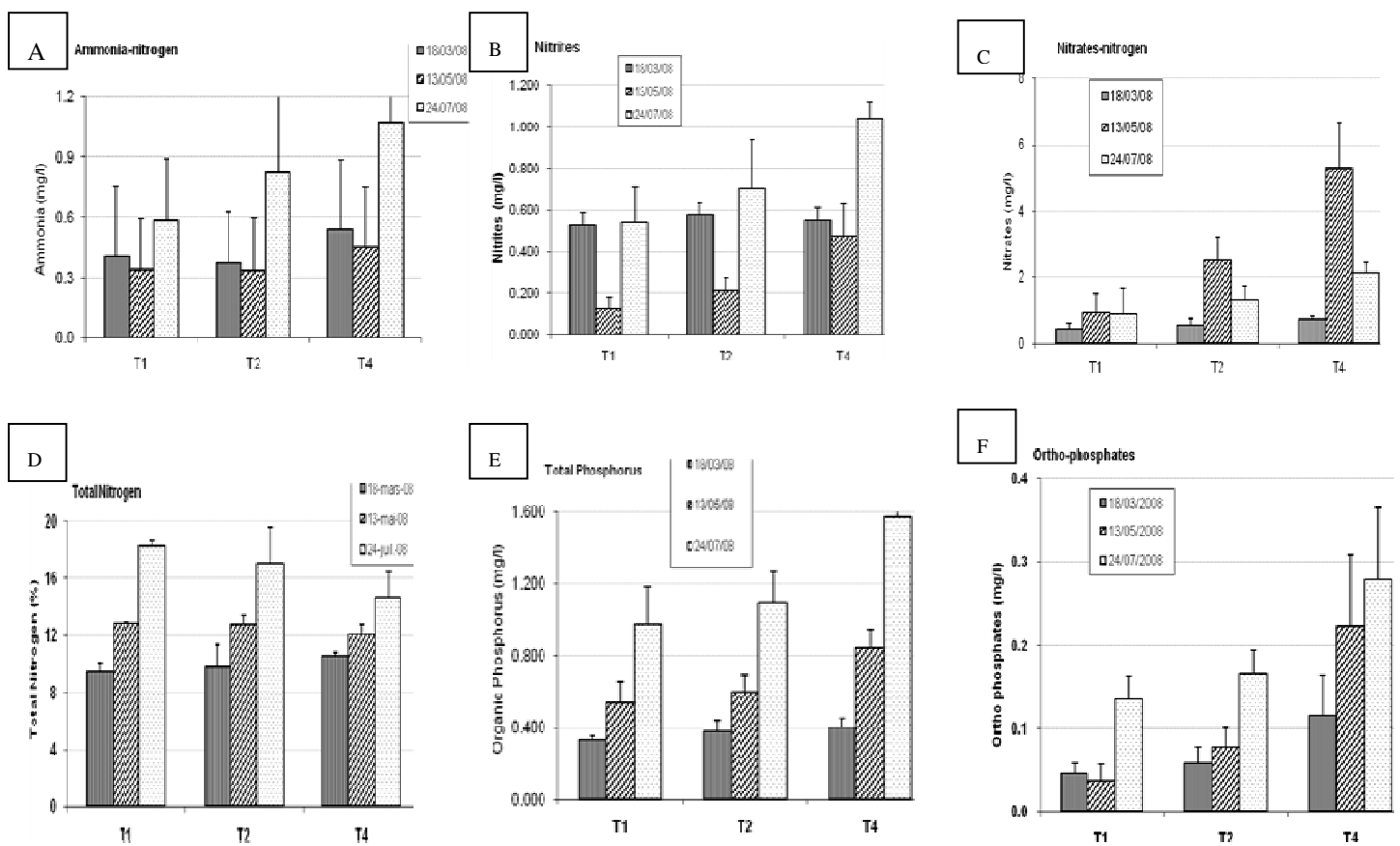


Figure 3.12. Changes of nitrogen and phosphorus nutrient forms in Nile tilapia ponds fertilised by rabbit droppings at three different rabbit densities on ponds: T1= 100, T2= 200, and T4= 400 rabbits per hectare of pond) for nearly 5 months.

3.3.3 Effects of rabbit droppings on the nutrients in fishpond mud

Total nitrogen and total phosphorus concentrations were clearly low in all treatments. Total nitrogen and total phosphorus concentrations increased over time; concentrations at the end date were significantly higher ($P < 0.001$) than those at the starting date in all treatments (Figure 3.13). Concentration values in TN lay between 0.04 and 0.06 mg.l^{-1} at the start of the experiment, and between 0.10 and 0.14 mg.l^{-1} after 5 months of fertilisation. There was no significant difference between treatments ($P = 0.785$).

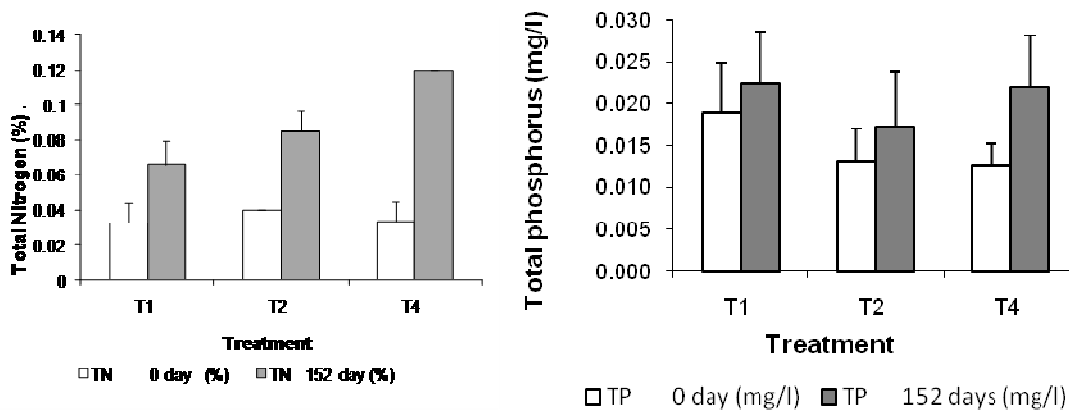


Figure 3.13. Trends in total nitrogen (left) and total phosphorus (right) in sediment of fish ponds fertilised with T1= 100, T2= 200, and T4= 400 rabbits per .hectare of pond.

3.3.4 Effect of rabbit droppings on fish growth and production

3.3.4.1 Fish production

Mean fish weight of the Nile tilapia was not significantly different among treatments ($P < 0.05$) at the end of the experiment (Table 3.5). Regression made for rearing days and fish weight showed that treatments explained the variance in fish weight increase for 91.9%, the weight in all treatments increased significantly ($P = 0.003, 0.001$ and 0.000) respectively for T1, T2, and T4. The steepest slope was presented by T4 as the regression equation displays $Y = -78.71 + 0.21T1 +$

$0.37T2 + 0.46T4$. The fish yield obtained in this study was low and ranged between 4.61 and 6.35 $\text{kg}\cdot\text{are}^{-1}$.of pond. This corresponded to a projected annual production of between 11.34 and 18.38 $\text{kg}\cdot\text{are}^{-1}\cdot\text{yr}^{-1}$ that is 1.1–1 8 $\text{t}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$. The treatment that received droppings from higher rabbit stocking rate (T4) was higher ($P<0.05$) in terms of fish yield than T1 and T2 (Table 3.5).

3.3.4.2 Fish growth performance

Fish growth was assessed through the daily weight gain (DWG in $\text{g}\cdot\text{day}^{-1}$), the specific growth rate (SRP in $\%\cdot\text{day}^{-1}$), and the survival rate (SR) in all treatments.

The mean DWG was low in all treatments, which ranged from 0.10 to $0.15\text{g}\cdot\text{day}^{-1}$, but the SR (%) was high (80–93.3%) with no significant difference among treatments for both DWG and SR. Nevertheless, the highest value was always present in T4 (Table 3.5). On the other hand, treatments were all significantly different ($P<0.05$) for SGR. Treatment T4 was significantly higher ($P<0.001$) than the others following this order: $T4>T2>T1$ with relatively low mean values $0.77>0.58>0.43 \%\cdot\text{day}^{-1}$ (Table 3.4).

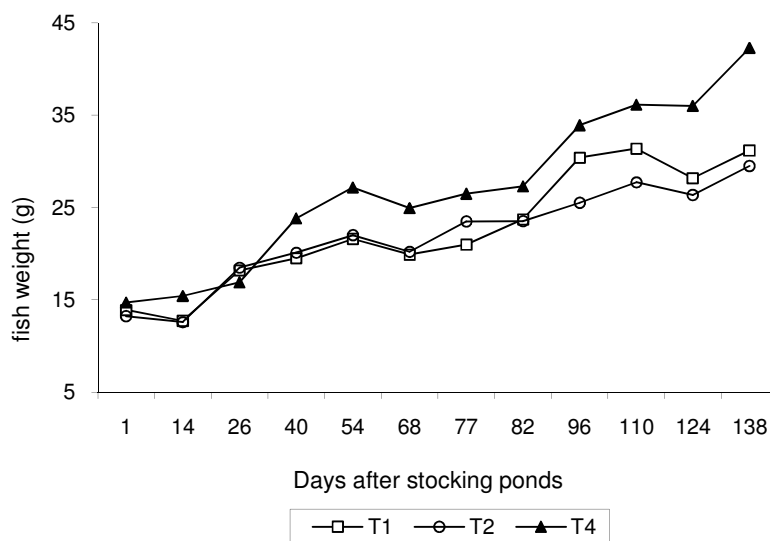


Figure 3.14: Trends in mean weight of Nile tilapia reared in earthen ponds fertilised by rabbit droppings from three different stocking densities: T1= 100, T2= 200, and T4= 400 rabbits per .hectare of pond for nearly five months.

Table 3.5: Growth and Production performance of Nile tilapia reared in earthen ponds fertilised by rabbit dung at 3 different densities for nearly five months. Values are average \pm std error of mean.

Pond stocking time

Treatment	Number of fingerlings	Mean weight (g)	Biomass
T1	707	13.9 \pm 0.49	9.8
T2	753	13.2 \pm 0.61	10.07
T4	800	14.7 \pm 0.40	11.8

Harvesting time (140 days later)

Treatments	Number of fingerlings	Mean weight (g)	Biomass (kg)	Yield (kg. are ⁻¹)	DWG (g.day ⁻¹)	SR (%)	SGR (day ⁻¹)	(%)
T1	566	31.7 \pm 6.5	17.90	5.1 \pm 0.78	0.1 0.02	79.82 \pm 4.33	0.4 \pm 0.15 ^a	
T2	667	29.5 \pm 0.59	19.66	4.6 \pm 0.44	0.1 \pm 0.01	85.2 \pm 6.54	0.6 \pm 0.04 ^b	
T4	747	42.3 \pm 2.73	31.60	6.5 \pm 0.44	0.1 \pm 0.00	93.4 \pm 3.06	0.8 \pm 0.04 ^c	
LSD	5%				ns	11.59 ns	0.14*	
level								

n.s = Non significant, * = significant difference, ** = highly significant difference. g.day⁻¹: gramme per day, %.day⁻¹: percentage per day. Data that have the same superscript letter in the same column are not significantly different at 5% level of confidence (p<0.05).

3.4 Discussion

The objective of the research was to contribute to the optimisation of an integrated system of rabbit–fish–rice, starting by assessing the quality of pond water and sediment, the fish growth and production in ponds fertilised by rabbit droppings (dung and urine), and the rabbit production over fishponds considered to be in harsh living conditions by a number of researchers. The dynamics of a fishpond lie in the variation of not only nutrient (biogenic elements) concentration but also physico-chemical parameters which modification should be subject to fertilisers being discharged in, and impact on the growth and production of reared fish.

The present study was conducted on rabbits reared in conditions where the average annual temperature generally ranges between 14 and 28 °C and the monthly relative humidity ranges from 59 to 83%, which includes “the comfort zone” of 21 °C temperature and 60 to 65% humidity level (Fayez *et al.*, 1994; Lebas *et al.*, 1996). However, the marshland is subject to frequent fluctuations that can sometimes lower the temperature to below 12 °C or increase rabbit hutch temperatures to higher than 35 °C. These conditions compromise their growth performance as well as fish production in ponds. Although average climatic conditions are quite good for rabbits in the Rwasave marsh, large fluctuations occur often, especially during the night where the temperature is always below 12 °C and sometimes is over 28 °C during the day. These are conditions that cause rabbits to curl up or to stretch out, thereby triggering the outbreak of enteritis, increase of feed intake, and decrease of food conversion rate, which, in turn, favours the proliferation of pathogens in the gut and production of lethal toxins (Fayez *et al.*, 1994; Lebas *et al.*, 1996). Crimella *et al.* (1991), in Yamani and Farghally (1994) reported a 4.2% weight loss due to high ambient temperatures and 3.8% weight loss for 70–75% relative humidity.

Even though data on rabbits reared in such conditions are scarce, or not available, in the literature, this study showed that the marsh weather conditions did not prevent rabbits from surviving (100–95% SR) and growing (11.5 to 9 g.day⁻¹ DWG); this is encouraging for rearing rabbits over such ponds in such conditions. Similar observations were reported by Matsiko (2004) who noted up to 13.3 g.day⁻¹ of DWG and high survival rates of rabbits under

wetland conditions and advised more care for young rabbits during high moisture period (rainy season). In addition, [Lebas et al. \(1996\)](#) pointed out the failure to manage the aggressiveness of either male or female within a group that led to a decrease in food intake. The experiment operated only on low densities so there was less or no stress at all arising from crowding; this explains why better growth and performance were observed in T1 for all measured parameters (mean weight, DWG, SGR, and SR). Moreover, the experimental rabbits were fed on forage *ad libitum* as indicated to be the best feed ever for sustainable rabbit husbandry ([Lukefahr, 2007](#)). Rabbits have the ability to utilise various by-products, and they are 2.5 to 4 times more efficient in extracting proteins from forage than sheep and beef cattle ([Samkol and Lukefahr, 2008](#)).

Rabbit dung and the physico-chemical quality of fishpond water

The importance of rabbits in integrated fish farming is to serve as a source of manure, an organic fertiliser that decomposes into water and releases nutrients. This creates an oxygen demand ([Boyd and Tucker, 1998](#)). When rabbit droppings have decomposed in fishponds, they enrich water with nitrogen in the form of ammonia, nitrites, and nitrates. The nitrogen in water favours microbial activities that result in a change in the whole physico-chemical composition of the fishpond water. Temperature, water transparency, dissolved oxygen, and pH concentrations obtained for these parameters remained in the range required for sustainable fish production. No significant differences were recorded among treatments for all these physico-chemical parameters. However, mean water temperatures were low (about 22°C) and showed a fluctuation from 20.0 to 25.3°C, the highest temperature being in T4. The lack of differences here indicates that stocking rates influenced water quality similarly. This suggests that the rates used were quite low. Further research on the optimisation of suitable higher rabbit stocking rates is needed as those tested here proved to be too low.

Mean dissolved oxygen concentrations averaged 5 mg/l, but the minimum recorded in each treatment shows a trend of eutrophication: 1.67, 1.59 and 1.41 mg.l⁻¹ for T1, T2, and T4, respectively, are under the minimum acceptable levels of dissolved oxygen concentrations set at under 3 mg.l⁻¹ for fish ([Mmochi et al., 2002](#)). Lower DO concentrations were measured during morning hours indicating microbial activity that consumes oxygen during the night while daytime DO averaged 8 to 10 mg.l⁻¹ due to photosynthesis by phytoplankton ([Boyd and Queiroz, 2001](#);

Mmochi *et al.*, 2002; Tepe and Boyd, 2002). Ponds getting an increasing quantity of organic matter entertain continuous degradation reactions that decrease the concentration of dissolved oxygen and increase available dissolved nutrients in ponds (Tepe and Boyd, 2002; Tucker and Hargreaves, 2003). The mean pH obtained ranged between 6.5 and 6.7, which is within optimum limits for fish growth, but it increased during the day (that is, pH = 9.1 in T4), probably due to the phytoplankton that utilise and consume carbon dioxide for photosynthesis. Morning pH was relatively low due to the respiration of living organisms during the night discharging carbon dioxide in ponds. A noticeable trend of a decrease in dissolved oxygen is pointed out as relative to fertilising time (Franco, 1991; Boyd and Queiroz, 2001; Mmochi *et al.*, 2002). pH fluctuations also explain what happens regarding dissolved oxygen in these ponds receiving rabbit dung when morning DO were very low in ponds with the higher density of rabbits over ponds. However, neither pH nor DO levels in the tested rabbit stocking rates reached harmful values that would require preventative measures.

Results obtained for the primary productivity in ponds fertilised by rabbit droppings over ponds at a density of 1, 2, and 4 rabbits per are (i.e 100 m²) were lower than previously found in ponds receiving dried rabbit dung from a remote source. The primary productivity in our ponds were 286.28 and 321.28 mgC.m⁻².day⁻¹ as against 0.69, 0.75, 0.70 gC.m⁻².day⁻¹ (Franco, 1991) for the control, 50 kg and 75 kg loads of rabbit dung and 0.93 and 1.3 gC.m⁻².day⁻¹, reported for a tropical pond system (Teichert-Coddington, 1991, in Franco, 1991).

Physico-chemical parameters measured during our experiment did not show limitations to the primary productivity in general, such as pH [6.5–6.7]. The observed trend of declining transparency could normally meet an increasing trend in primary production but results suggest that there may be another source of turbidity than phytoplankton for the decrease in transparency for the pond water was brown most of the time. Water alkalinity was high enough (45–73 mgCaCO₃/l) to increase primary productivity if we refer to McNabb *et al.*, (1989) and Boyd (1979) quoted by Rwangano (1990). These authors reported an increasing phytoplankton production infertilised ponds of 20–60 mgCaCO₃/l while no correlation between total alkalinity and algal productivity was observed in ponds with alkalinity values of 20–120 mgCaCO₃/l.

Considering the history of used ponds, suspended inorganic particulates and clay in suspension might have raised pond turbidity and blocked sun radiation from boosting algal photosynthesis (Boyd and Tucker, 1998; Tepe and Boyd, 2002). These observations support the findings that none of the three treatments with rabbit droppings in this study reached a high level of plankton production and prompt the use of higher stocking rates in rabbits. Rabbit manure dropped continuously into fishponds brings in nutrients. The quantity and quality of nutrients consumed in animal diets will primarily reflect the composition and quality of nutrients available (Van Horn, 1998). Given the fact that rabbit manure is ten times higher in nitrogen than that of cow dung, rabbit manure sustains better plankton production by releasing nutrients gradually into water (Kumar and Ayyapan, 1998). Our experimental ponds were also old and have been used for reproduction of tilapia being fertilised by manure from goat and sheep, and various grass. However, as stated earlier, they were drained to alleviate any effect that would be caused by their previous use.

Rabbit urine is a good source of N and P as it contains 50% of the total nitrogen, 6% of the phosphorus, and 60% of potassium provided by rabbit droppings. Furthermore, the nutrients in urine are more readily available to the plankton than the nutrients in solid excrement (Van Vleet, 1997). In this integrated system, fishpond water receiving droppings from rabbits was enriched continuously, mainly in nitrogen-nutrients and phosphorus-nutrients after bacterial decomposition in water. Most nutrient concentrations increased significantly with time in all treatments except nitrate–nitrogen. This indicated the positive role that rabbit droppings play in fertilising fishponds as was previously noticed by several authors (Franco, 1991; Breine *et al.*, 1996; Kumar and Ayyapan, 1998; Little and Edwards, 2001). None of the treatments resulted in any nutrient increasing to maximum allowed concentrations for the protection of fish life. Breine *et al.* (1996) reported little or no effect on ammonia and nitrite concentrations. These remained lower than the limit for harmful concentrations for Nile tilapia.

It should be noted, however, that ammonia-nitrogen increased significantly in T4, as did the total alkalinity that supported microbial activity which was most important in T4. The same pattern was observed for nitrite–nitrogen but its concentrations did not rise above 1.0 mg.l^{-1} , which is much lower than 5 mg.l^{-1} considered lethal for Nile tilapia (Losordo, 1997). Very high nitrites are

reported in ponds where pH tends to be acidic due to acidic soil or the accumulation of humus preventing bacteria from helping organic matter to decompose. In Rwasave marsh, soil pH is slightly acidic (4.5–6.5) but the ponds have changed due to fertilisation over the last 25 years.

Mean nitrate–nitrogen were relatively highly concentrated (0.76, 1.46, and 2.72 mg.l⁻¹ for T1, T2, and T4 respectively) and decreased significantly with time in our rabbit–fish system compared to 0.16, 0.12, 0.39 mg.l⁻¹ when Rwasave ponds were fertilised with cow dung mixed with compost, with green grass, and with compost respectively by [Rwangano \(1990\)](#) and 0.12, 0.11 mg.l⁻¹ ([Tepe and Boyd, 2002](#)) when treating ponds with ammonium sulfate and sodium nitrate. This indicates that rabbits on ponds did not negatively influence the quality of fishpond water on the one hand, but it resulted in low primary productivity on the other hand, which may have affected fish growth performance. Concentrations of soluble reactive phosphates were quite similar to phosphorus in ponds fertilised by green grass and chemical fertiliser ([Tepe and Boyd, 2002](#)) which could not produce enough phytoplankton bloom. Many authors agree that soluble reactive phosphorus–only treatments are adequate for good fish production ([Swingle *et al.*, 1965](#), [Murad and Boyd., 1987](#), cited by [Tepe and Boyd , 2002](#)). According to [Mortimer \(1954\)](#); [Hickling \(1962\)](#); [Hepher \(1963\)](#); [Arce and Boyd \(1975\)](#), in [Tepe and Boyd \(2002\)](#); nitrogen fertilisation is not as important to fish production as is phosphorus fertilisation.

Rabbit dung on the quality of pond sediment nutrient (Nitrogen and Phosphorus)

Bottom soil of ponds receiving rabbit droppings were significantly enriched in total phosphorus and soluble phosphorus as well as in total nitrogen. The magnitude of increases in TP and SRP were three and two times higher in T4 than in the two other treatments for TN and SRP. According to [Boyd \(1979\)](#) pond bottoms do not accumulate large amounts of organic matter supplied because the matter is converted into carbon used by bacteria to produce CO₂ for photosynthesis. However, nitrogen is lost primarily by denitrification or volatilisation, whilst mostly phosphorus is strongly adsorbed by pond soils or precipitated as calcium phosphates ([Mansouda and Boyd, 1994](#); in [Boyd and Queiroz, 2001](#)). These nutrients were the only ones assessed because of their importance in ponds' production capacity. Additional nutrients in ponds are the silicates, carbonates, chloride, and sulphates mostly brought in by various organic matter

as well as soil substrates. Silicates are materials that build some of the plankton groups (Bacillariophyta) in ponds.

Rabbit dung on fish production performance

In general, growth and production of Nile tilapia remained low. Reports on growth were 14.7 g to 42.3 g mean weight, a SGR of $0.77\% \cdot \text{day}^{-1}$, with a high survival rate (93%) recorded in treatment T4 which presented the best projected net fish productivity of $18.38 \text{ kg} \cdot \text{are}^{-1} \cdot \text{yr}^{-1}$ that is about $1.84 \text{ t} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$. Multiple regression analysis on fish weight and rearing days confirms the results on mean weight increase in time showing significant differences between treatments ($P = 0.000$, 0.001 and 0.003 respectively for T4, T2, and T1); T4 having the steepest slope. Taken together, the three rabbit load rates explain variance in fish weight growth of about 91%.

Fish growth and production were in the same range as other reported growth for tilapia from ponds fertilised with duck, chicken and goat manure in China, Bangladesh, and India (Quazi and Huque, 1991). However, specific growth with rabbit dropping fertilisation was slightly higher than that for fertilisation with cow dung, grass, and compost and also higher than that for biodigester effluent from cow and rabbit dung (Mahadevaswamy and Venkataraman, 1988). This is not surprising, as rabbit manure is more concentrated in phosphorus and nitrogen components than other animal manure (Lebas *et al.*, 1996), and its nitrogen is reported to be 10 times higher than that of cow dung (Kumar and Ayyapan, 1998). Fish growth and production performance are always attributed to the farming environment including biological, and physico-chemical quality of the medium.

Parameters discussed above have led to better Nile tilapia growth linked to relatively high number of rabbits in this experiment. Many studies reported a close relationship between net fish yield and chlorophyll a for primary productivity in fertilised ponds as well as fish feeding regime, (Rwangano, 1990; Boyd, 1979; Gross *et al.*, 1999; Little and Edwards, 2003). The performance reported here can be considered as the lowest possible because the loading rate in rabbits did not bring the ponds to a high level of primary production, alkalinity, and phosphates that favour filter feeder fish like Nile tilapia. More studies on other rabbit loading rates are needed to clearly establish the effect of different rates on the quality and management of fishponds.

3.5 Conclusion

The success in a fish farming enterprise lies in the comprehension and implementation of adequate techniques that enable the farmer to successfully maintain water quality, correct fertilisation, and feeding, as well as handle stock on the farm.

From this study, a better environment for fish (Nile tilapia) production has been established. Unexpected results for some physico-chemical patterns showed, however, that certain set treatments were not able to be fully explained. Further experiments should be undertaken in order to optimise load rates that can improve pH and dissolved oxygen concentrations to avoid limiting the nitrifying process and total alkalinity for a better use of carbon by primary producers in ponds. Nevertheless, the stocking rate with 4 rabbits per are (400 per hectare) was promising as it managed to provide conditions that led to fish productivity closer to those using other sources of fertilisation (green grass, ducks, chicken, pig, and goat). Even though productivity is still lower than that of other semi-intensive and intensive aquaculture using high quality concentrates, this IAA system (rabbit–fish system) can be applied with confidence to production by rural small-scale fish farmers rather than throwing up one’s hands fearing the cost of inputs (feed concentrates, duck, and poultry manure). In addition, the system opens to an opportunity of extending the integration using the fertilised pond water to irrigate crop, therefore adding one more levels of production. This requires a better understanding of all the resources involved as well as their functioning.

In this way, the proposed rabbit–fish system is suited to reducing the expense of concentrated feeds and providing a more balanced natural diet to filter feeder fish such as Nile tilapia, while maintaining a safe environment and thus ensuring the sustainability of production. Further studies on rabbit–cum–fish system are needed to better understand the functioning of the integrated system, and provide better practices to exploit all available resources in order to increase the production in all components of the system.

Acknowledgements

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4. CHAPTER FOUR: Resource Flow and Use of Nile Tilapia Pond Effluent as Fertiliser Input in an Integrated Rabbit–Fish–Rice System

The following article is based on the chapter 4:

RukeraTabaro, S., Mutanga, O., Rugege, D., and Micha, J.-C. n.d. (*in review*). Resource Flow and Use of Nile Tilapia Pond Effluent as Fertiliser Input in an Integrated Rabbit–Fish–Rice System in Rwanda. *Agriculture, Ecosystems and Environment*.

Abstract

An assessment of the flow of resources and Nile tilapia wastewater reuse was conducted on an agriculture–aquaculture integration system named the integrated rabbit–fish–rice system (IRFR). The study aimed at providing practical knowledge based on the functionality of the integration of rabbit husbandry, tilapia and rice culture by way of irrigation, in order to improve the food security of poor farmers in developing countries using available means.

Fishponds, fertilised by droppings directly excreted by rabbits reared over ponds, were stocked at one, two, and three fish per m² with Nile tilapia (*Oreochromis niloticus* L.). The rabbits received grass only, cut in the environs of fishponds. Pond effluent was canalised to fertilise three rice fields while the other three were irrigated by canal water and three with inorganic fertilisers. The fish growth was found to be density-dependent and the best fish yield (1.3 t.ha⁻¹) was recorded from the highest stocking rate. Experimental yields showed that pond effluent led to significantly higher rice yield (10.5 t.ha⁻¹.crop⁻¹) than that from water canal alone, and did not significantly differ from the inorganically fertilised rice yields (8.2 t.ha⁻¹.crop⁻¹). On-farm resources surpassed off-farm and accounted for 89.0% of the total N and 92.3% of the total P input.

The study suggested that integrated rabbit–tilapia–rice systems could be viable and adopted by poor farmers. Pond management practices could focus on the monitoring of various flows in order to increase resources intelligently for better production and improve profitability for farmers while mitigating threats to the environment.

Keywords: Flux of resources. Wastewater reuse. Tilapia and rice yield performance. Fish stocking density. Integrated Rabbit–Fish–Rice system.

4.1 Introduction

The combination of aquaculture, crop and livestock is most advisable in countries with scarcity of land. This system known as integrated aquaculture–agriculture system (IAA) is often considered a sustainable agriculture model for poor farmers (Prein, 2002; Nhan *et al.*, 2008). However, concern has been raised over the potential eutrophication of natural waters as a result of the intensive aquaculture and some IAA systems. According to Boyd and Queiroz (2001), the water that is discharged from fishpond effluent into the environment is always enriched with nutrients, organic matter, and suspended solids, and these wastes from cages and pens enter into natural waters. Tucker and Hargreaves (2003) have also found that only 20–30% of the nutrients in consumed feed input is retained in fish biomass, while the remainder is added to non-consumed material (that is, uneaten feed and fish faeces) and released into the pond environment in the form of organic matter, dissolved nutrients, and fish faeces.

Many treatments of aquaculture effluents have been used in many countries to alleviate the impact of nutrient pollution due to aquaculture (Kristiansen and Cripps, 1996, in Yi *et al.*, 2006). However, the costs for waste treatment techniques are not affordable for most of the fish farms in developing countries. Therefore, there is need of suitable techniques that require little investment while being environmentally friendly.

In this regard, nutrient-rich effluent from intensive aquaculture in catfish ponds have been reused as fertiliser input to semi-intensive tilapia culture (Yi *et al.*, 1996; Yi *et al.*, 1998; Lin and Yi, 2003; Yi *et al.*, 2006) or used as fertiliser for rice fields through irrigation of the rice field by pond effluent; with a reported result of 368 kg/400 m² pond for 105 days of catfish growths, with a daily weight gain of 1.05g and 2.8–3.1 t.ha⁻¹ of rice grain yields. Furthermore, a study on the economic implications of various practices such as wastewater treatment (Kouka and Engle, 1996) showed that the use of pond effluent to irrigate crops was most effective. However, very few studies on the use of Nile tilapia pond effluent are found in the literature. Among the rare works found, Wood *et al.* (2000) irrigated French beans with effluent from fish polyculture (*Tilapia aureus* x *C. gariiepinus*) ponds and reported good yield (4.3 t.ha⁻¹), pointing out that tilapia ponds supplied inadequate amount of nutrients to produce high yields. No study has until now been conducted on the reuse of tilapia pond effluent in tropical conditions, although Nile

tilapia remains the most appreciated fish in the region, and in Rwanda in particular. [Prein \(2002\)](#) indicated that, and this is the case in Rwanda, rural areas tend to be occupied by poor farmers who only have small land holdings. These farmers have limited financial resources and knowledge of better agricultural techniques; hence, they are loath to take any risks. They then need to be taught suitable IAA technologies that will require little risk on their part, are easy to replicate, require little investment, and help to realise a quick return ([Haylor, 2000, in Prein, 2002](#)).

In Rwanda, over the last five years, the development of rice culture has increased the size of converted marshland area into rice fields and consequently various facilities for IAA systems are available. These facilities include dams, irrigation reservoirs, and the rice field itself, but Rwandan rice farmers still do not exploit these resources due to a lack of aquaculture technical skills and the fear of the risks involved in aquaculture.

The present study intends to contribute towards improved food security by increasing food production at low cost through the use of an integrated rabbit–fish–rice (IRFR) system suitable for poor fish farmers. The study focused on the resource flow throughout the IRFR system aiming at highlighting all sources likely to fertilise the tilapia pond thus improving fish production and the agricultural crop (that is rice) through integrating fish farming into the irrigation system ([Fernando and Halwart, 2000](#)). Rabbits have shown the potential to fertilise fish ponds hence maintaining good water quality for Nile tilapia (chapter 3). Fishpond water fertilised by way of the droppings that come from rabbits that are reared in hutches built over the fishponds, is then used to irrigate the rice fields downstream which, in turn, retain the nutrients that would otherwise be discharged into the natural environment (that is, natural water bodies). The fishpond effluent is important resource, which together with others in the system need to be studied for a sustainable management.

The objective of the paper was to assess (1) The bio-resource flow within the IRFR system, (2) the growth and production of fish in ponds, and rabbit housed over fishponds, (3) pond changes in the water and mud quality, (4) and the rice growth and production as influenced by fishpond effluent flow.

4.2 Materials and Methods

4.2.1 Site description

The study was conducted using the research ponds of the Rwasave Fish Culture Research Station (SPIR) of the National University of Rwanda (NUR) in Butare, Rwanda. The SPIR is geographically located at 02° 36' 10" S and 29° 45' 25" E at an elevation of about 1,625 m above sea level, in the Huye district of the southern province of Rwanda (Figure 3.3).

4.2.2 Experimental setup

The study was conducted using mainly three different living organisms, namely the rabbit (*Oryctolagus cuniculus* L.), the fish (Nile tilapia, *Oreochromis niloticus* L.), and rice (*Oryza sativa* L., the *Yuni Yin4* variety), all farmed as components of a fully integrated agriculture–aquaculture (IAA) system.

Nine 400 m² (4 ares) earthen ponds with an average depth of 1.0 m of the Rwasave Fish Culture Research Station were used. The large dyke adjacent the ponds, downstream, were transformed into 9 rice plots of 90 m² (9 m x 10 m) (Figure 3.2). Three of the ponds were connected to three rice fields by way of polymer of vinyl chloride (PVC) pipes for irrigation.

The ponds were stocked with hand sexed juveniles of Nile tilapia, averaging 38.4 g, and three different stocking densities were replicated three times, that is, pond treatments PT1 (1 fish.m⁻²), PT2 (2 fish.m⁻²), and PT3 (3 fish.m⁻²) were applied. Three treatments were also applied to the rice fields in a complete randomised design: (1) Rice treatment RT1: three rice fields receiving water from the canal without any fertiliser, (2) RT2: 3 rice fields fertilised by NPK 17:17:17 and Urea (45% N); (3) RT3: three rice fields fertilised by fishpond effluent. Effluent and water canal were applied once a day for the irrigation of the rice field to maintain the level of water.

All fishponds were fertilised by rabbit droppings (urine and dung) excreted directly by 16 rabbits (700–1000 g live weight) housed over each fishpond of 400 m², and 24 rabbits over fishponds of 600 m² of surface area (that is, a density of 400 rabbits.ha⁻¹ of pond). Rabbits were fed on a mixture of 25 identified species of grass, *ad libitum*, among which 15 species belonging to four

families were most abundant and available, but with a slight decrease during the dry season, from the surroundings of the fishponds (Table 4.1). Among the 15 species of grass, 9 were of the *Asteraceae* family and the rest were represented by 1 species each from the *Amarentaceae*, *Brassicaceae*, *Convolvulaceae*, *Fabaceae*, *Polygonaceae*, and *Apiaceae* families.

Table 4.1: Identification of forage used to feed rabbits during experiments on integrated rabbit–fish–rice as an IAA system in Rwanda in 2008–2010 (Rwasave Fish farming and Research Station)

Family	Scientific name	Vernacular name	Presence in the field
Asteraceae	<i>Crassocephalum montuosum</i> (S. MOORE) MILNE-REDH	Igifuranindacy'akabande	###
Asteraceae	<i>Emilia sp1</i> CASS.	Karabukirwa (A) with orange flour	###
Asteraceae	<i>Emilia sp.2</i> CASS.	Karabukirwa (B) with yellow flour	###
Asteraceae	<i>Bidens pilosa</i> L.	Inyabarasanya	###
Asteraceae	<i>Leonotis nepetifolia</i> (R. BR.) AITON f.	Igicumucumu	###
Asteraceae	<i>Lactuca sp. L.</i>	Rulira	###
Asteraceae	<i>Guizotiascabra</i> (VIS.) CHIOV.	Igihehicy'inshikashike	###
Asteraceae	<i>Adenostemma mauritianum</i> DC.	Kimari	###
Asteraceae	<i>Erlangeaspissa</i> S. MOORE	--	##
Asteraceae	<i>Spilanthus mauritiana</i> (RICH. ex PERS.) DC.	Ubushwima	#
Asteraceae	<i>Crossocephalum vitellinum</i> (BENTH.) S. MOORE	Umusununu	#
Asteraceae	<i>Conyzapyrrhopappa</i> SCHULTZ-BIP. ex A. RICH	Umungangu	#
Asteraceae	<i>Ageratum conyzoides</i> (L.)	Umubuza	#
Fabaceae	<i>Desmodium intortum</i> (MILLER) URBAN	Igifashicy'inika	###
Fabaceae	<i>Crotalaria sp.</i>	Akayogeragato	#
Fabaceae	<i>Crotalaria sp.</i>	Umuyogera	#
Brassicaceae	<i>Brassica oleracea</i> var. <i>capitata</i>	choux	###
Polygonaceae	<i>Rumex sambarensis</i> (DAMMER) DAMMER	Igifumbafumba	###

Polygonaceae	<i>Rumex sp.</i>	Nyiramuko	##
Apiaceae	<i>Centellaasiatica (LINN.)</i>	Gutwikumwe	##
Oxalidaceae	<i>Biophytumhelenae</i> <i>BUSCAL. et MUSHEL</i>	Nyiramabumbabumba	#
Oxalidaceae	<i>Oxalis corniculata L.</i>	Munyuwanyamanza	#
Amaranthaceae	<i>Amaranthus sp.</i>	Imbwija, imboga	#
Amaranthaceae	<i>Althernanthara</i> <i>sp.KUNTH</i>	Umunyumbu	#
Convolvulaceae	<i>Ipomoea batata(L.) LAM.</i>	Imigoziy'ibijumba	##
Acanthaceae	<i>Asystasiagangetica (L.) T.</i> <i>ANDERSON</i>	Ijojwe	#
Onagraceae	<i>Ludwigia sp.</i>	Isogereza	#

Identification done by Dr E. Bizuru (Biology, Faculty of Sciences, National University of Rwanda) (#rare, ## abundant, ### very abundant in the environs of ponds at Rwasave marshland)

4.2.3 Bio-resource flow throughout the IRFR system

The description of the bio-resource flow characterising the rabbit–fish–rice system is detailed in Figure 4.1. The entrance point of the IRFR system is the rabbit feed, an on-farm input source that includes mainly grass, with rest cultivated crops and/or agroforestry tree leaves (1). The latter input source can also be an off-farm one, composed of leaves and grass cut on watershed (2), as well as formulated pellets.

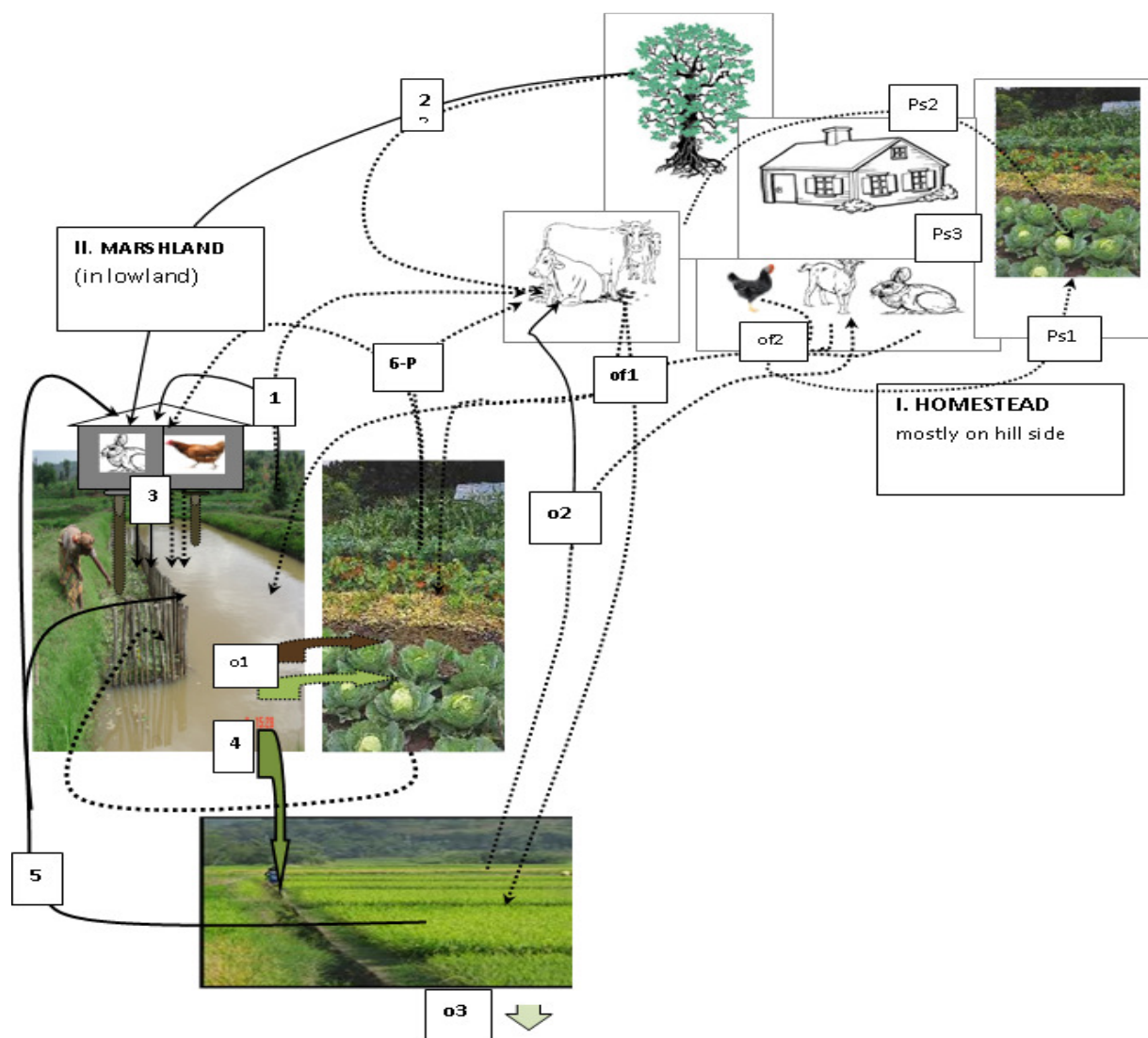


Figure 4.1: Bio-resource flow chart of the integrated rabbit–fish–rice system (IRFR) and other potential resource origins. **1,2,3,4,5:** all inputs within the IRFR(on-farm and off-farm sources); **6-P:** potential inputs; **of1,of2:** off-farm source of input; **o1,o2,o3:** output resource from the IRFR; **Ps1,Ps2,Ps3:** Potential sources from a remote place.

The main sources of nutrient input for the IRFR were the rabbit droppings (dung and urine) as an on-farm source, and the inflow from the stream (3) after rabbits had been fed with the grass. Among the resources that provided nutrients, nitrogen and phosphorus, the rabbit droppings and the inflow water accounted for 6.35% and 93.65% respectively for nitrogen sources, and 41.96% and 58.04% respectively for phosphorus sources. The rabbit forage contribution is implied in the dropping contribution and the effect of dried leaves that fall through the hutches into the ponds.

Enriched fishpond effluent (4) was a non-farm input for rice fertilisation. Other on-farm inputs were produced internally in the IRFR: enriched pond water effluent (4) for rice fertilisation; rice straw and rice bran for fish and rabbit or chicken consumption (5). The latter served at the same time and together with the pond sediment as outputs nutrient flow as fodder for animals, ingredient for pellet, vegetable garden watering, and garden soil improvement (o1, o2), the far distant output being the water seeping through rice field. The system can allow the integration to activities carried out in a remote place especially homestead farming activities. Their products and by-products are direct off-farm input (of1, of2) for both fishponds and rice field. Identified potential resources included animal manure, agro-forestry tree leaves and kitchen scraps (Ps1, Ps2, and Ps3).

4.2.4 Management of rice fields

4.2.4.1 The rice nursery and seedlings transplanting, and fertilisers application

The rice seeds (*variety Yuni yin4*), obtained from the Rwandan Institute of Agronomic Science (ISAR) rice programme, were sowed one day after application of NPK at 200 kg.ha⁻¹ in a 6 m² plot previously ploughed and leveled manually. The rice seedlings were transplanted 25 days after rice nursing at 20 x 20 cm spacing in accordance with [Vromant and Chau \(2005\)](#). Weeding was done twice only; that is, on the 15th day after transplanting (DAT) and at 45 DAT because the fields were permanently flooded hence almost weed free.

NPK (17:17:17) was applied twice at a rate of 200 kg.ha⁻¹ on the 2nd and 45th DAT and urea 45% N was applied at 100 kg.ha⁻¹ on the 15thDAT following the first weeding in accordance with [Vromant and Chau \(2005\)](#) as well as the ISAR rice programme. The water level in the rice fields

was kept at 5 cm height for 15DAT, and thereafter was raised to 15 cm height for the rest of the culture period; no water was discharged out of the rice field to allow total infiltration and therefore supply its nutrients to the soil before it reaches the underground. Water was added to fishponds to compensate for water used for irrigation and other losses. The rice growth was assessed by means of fortnightly height measurement of the rice straw and counting of the tiller number. At harvest grain was weighed and data recorded after being dried. A sample of 1000 grains was also weighed for a weight test in each treatment.

4.2.4.2 Water quality monitoring in fish pond

The quality of water was evaluated through fortnightly measurements of the physico-chemical parameters, including water temperature (°C), conductivity at 25°C ($\mu\text{S}\cdot\text{cm}^{-1}$), dissolved oxygen, and pH using appropriate probes WTW model. A Secchi disk was used for measuring water transparency. Fortnightly water samples were analysed for nitrogen forms and phosphorus forms. $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ were analysed according to the methods provided in the 15th edition of the American Public Health Association, (APHA, 1985). The total nitrogen (Boyd, 1979), and total phosphorus (Wetzel and Likens, 1979) were analysed in a non-filtered sample of water.

4.2.4.3 Soil quality sampling in fish pond and rice field and analysis

Three soil samples were collected in each fishpond and in each rice field at three different times: namely the start (before rabbit stocking), the midterm (92 days after rabbit stocking), and the end (124th day after stopping rice irrigation). Nitrogen nutrients (total nitrogen (TN), ammonia) were analysed according to methods adapted by Léonard and Kanangire (1998) from INEAC (1959) for TN, and McKeague (1978) for ammonia and nitrates. The total phosphorus (TP) and phosphates were analysed using the spectrophotometric method (Pauwels *et al.*, 1992b) and the blue-colorimetric method (Termminghoff, 2000b), respectively. The soil pH was measured by the electrometric method in a soil-solvent suspension, while the cations exchange capacity (CEC) were analysed on a saturated soil as detailed in IITA (1975, adapted by Léonard and Kanangire, 1998)

4.2.5 Statistical analysis

Measured parameters in the current experiment were assumed to change over time as well as differ among themselves. Each treatment being replicated, the analysis could only use mean values to show variability between treatments and according to time. Therefore, a two-way analysis of variance (ANOVA II) for parameters changing over time, especially for water quality, fish, and rice growth parameters was applied. Parameters that were assessed repeatedly, such as rice tillering and straw height, were analysed by ANOVA for repeated measurement that considers successive times of observation as a factor (Gomez and Gomez, 1984). ANOVA I was applied for fish and rice production parameters. Differences were considered significant at $P < 0.05$. Means were further tested using the least significant differences of means at a 5% level ($LSD_{0.05}$). All the analysis was performed using Genstat Statistical software (GenStat12.1 Ed[®], 2009. VSN International Ltd).

4.3 Results

4.3.1 Rabbits growth and droppings production

No difference in rabbit weight was found between groups of rabbit ($P > 0.05$) distributed over ponds of the three pond treatment. The overall rabbit mean weight increased from 703.5 ± 9.0 g to 1333.3 ± 35.2 g with a daily weight gain of $6.4 \text{ g} \cdot \text{day}^{-1}$ and the growth of all the group of rabbits followed the same trend (Figure 4.2). Likewise, the amounts of droppings excreted into the fishponds were not statistically different at 5% level ($P = 0.727$ for rabbit dung and $P = 0.905$ for urine) between the three pond treatments. Solid dung amounts increased with time in a similar manner for all pond treatments passing from 267.5 ± 57.30 g to 992.6 ± 126.0 g per 400 m^2 pond. The amount of urine increased during March to mid May, but decreased remarkably during May to June, due probably to the dry season that starts end of May. The change was similar in all treatments (Figure 4.2).

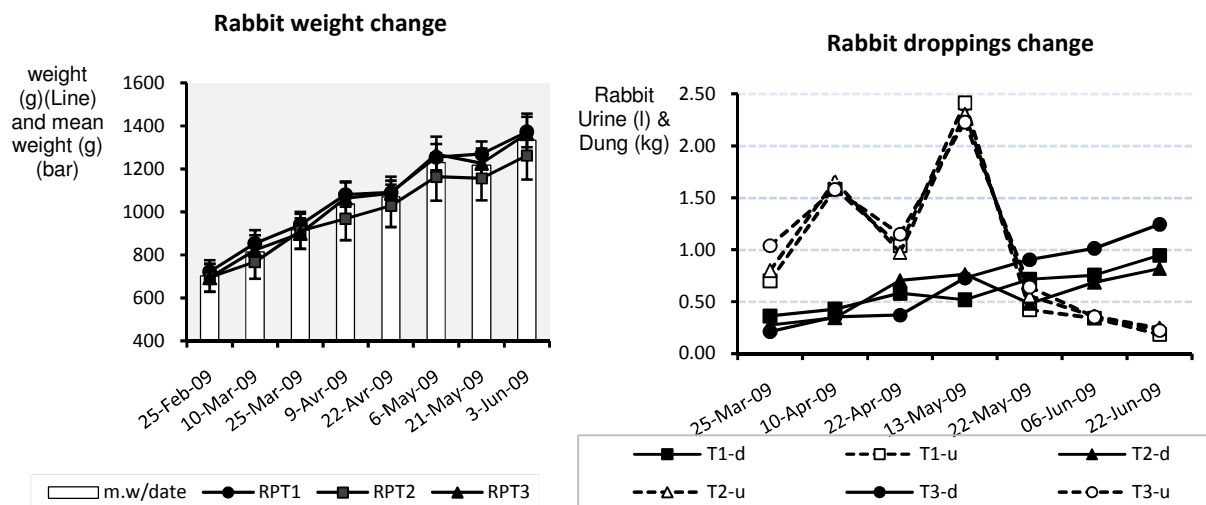


Figure 4.2: Trend of rabbit body weight g (Line) & mean weight per date (bar) [Left] and [Right]: droppings (kg of dung and litres of urine) excreted into a 400 m^2 fish pond per day (T1-d: rabbit dung that fertilised ponds of treatment PT1, T1-u: urine excreted into ponds of treatment PT1).

4.3.2 Nile tilapia growth and production performance

Nile tilapia juveniles reared in ponds under 1 fish.m⁻² (PT1) grew significantly faster ($P < 0.05$) than those under 2 fish.m⁻² (PT2) and 3 fish.m⁻² (PT3) (Figure 4.3) but in general, all treatments were characterised by a very low growth. The highest daily weight gain (0.33 g.day⁻¹) was performed by the lowest fish stocking rate, that is, treatment PT1 (Table 4.2).

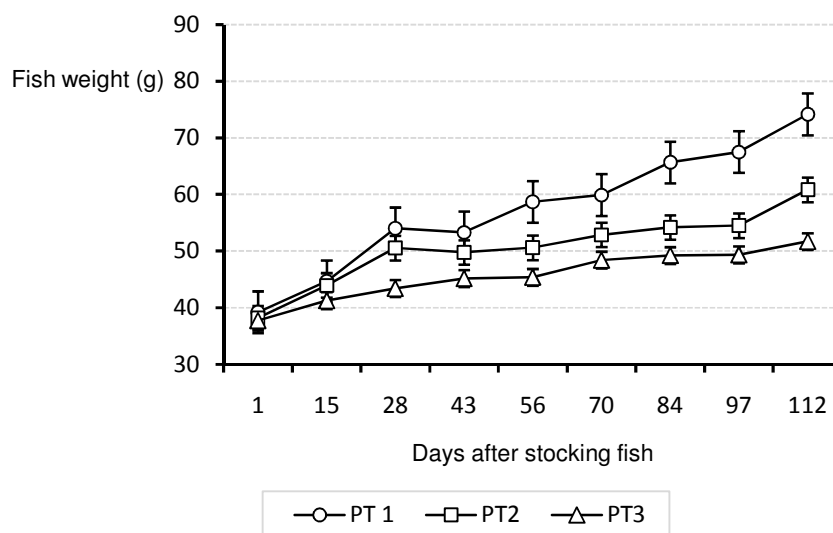


Figure 4.3. Fish growth over rearing time (evolution of mean weight) in fish ponds fertilised by rabbit droppings from 8 rabbits per 400m² pond and stocked with 1, 2, and 3 fingerlings per m² making treatment PT1, PT2, and PT3 respectively (error bars are made with standard error of means)

The treatment with the highest stocking rate (PT3) significantly higher yield ($P < 0.001$) than PT1 and PT2. However, the net fish production (NFP) ranged from 3.35 ± 2.4 to 6.19 ± 1.5 kg. are⁻¹. yr⁻¹ (i.e 335–619 kg.ha⁻¹.yr⁻¹) and PT3 performed the lowest NFP than the other two treatments but no significant differences were found among them ($P < 0.05$) (Table 4.2).

Table 4.2: Growth and production performance of male Nile tilapia stocked at 1, 2, and 3 fish m⁻² surface pond fertilised by rabbit droppings PT1: 1 fish.m⁻², PT2: 2 fish.m⁻², and PT3: 3 fish.m⁻²

Growth performance		Treatments				
		PT1	PT2	PT3	<i>P val</i>	<i>LSD</i> _{0.05}
Initial mean weight	g.fish ⁻¹	39.2 ± 0.6	38.2 ± 0.9	36.6 ± 0.7		
Final mean weight	g.fish ⁻¹	75.8 ± 4.1 ^a	56.1 ± 9.1 ^b	50.2 ± 4.4 ^b	(*)	16.59
Specific growth rate	%.day ⁻¹	0.6 ± 0.05 ^a	0.3 ± 0.08 ^b	0.3 ± 0.07 ^b	(*)	0.26
Daily weight gain	g.day ⁻¹	0.3 ± 0.04 ^a	0.2 ± 0.06 ^b	0.1 ± 0.04 ^b	(*)	0.16
Mean weight gain	g.fish ⁻¹	36.6 ± 4.6 ^a	18.0 ± 5.9 ^b	11.7 ± 3.8 ^b	(**)	14.3
Survival rate	%	76.6 ± 3.6 ^a	83.8 ± 2.4 ^a	85.0 ± 2.9 ^a	(NS)	
Total harvest biomass	kg	26.8 ± 2.6 ^a	42.9 ± 7.4 ^b	60.1 ± 5.7 ^b	(**)	14.16
Yield	kg.are ⁻¹	5.8 ± 0.2 ^a	9.3 ± 0.8 ^b	13.0 ± 0.6 ^c	(***)	2.38
Net fish production	kg.are ⁻¹ .yr ⁻¹	9.2 ± 1.0 ^a	9.9 ± 3.19 ^a	12.2 ± 2.5 ^a		8.4

PT1: pond treatment with 1 fish.m⁻²; **PT2:** Pond treatment with 2 fish.m⁻²; **PT3:** Pond treatment with 3 fish.m⁻², **-g.day⁻¹:**gram.day⁻¹; **-kg.are⁻¹.yr⁻¹:** kilogram per are (100m²) per year. Values are means ± SE of three fishponds for each treatment. Different superscript letters within one row denote statistically significant differences (P < 0.05).

4.3.3 Rice growth and production performance

During the 160 days of rice culture period, rice fields irrigated with water, but without any other fertilising input (RT1), showed significantly less tillers and shorter straws (P=0.004) than those in rice fields fertilised with NPK and urea (RT2) and those irrigated with fishpond effluent (RT3). The rice straw height in RT1 (height: 55.20 cm) was significantly shorter (P=0.001) than in RT2 (60.8 cm) and in RT3 (62.78 cm) among which (RT2 and (RT3) no differences (P>0.05) were observed (Figure 4.4).

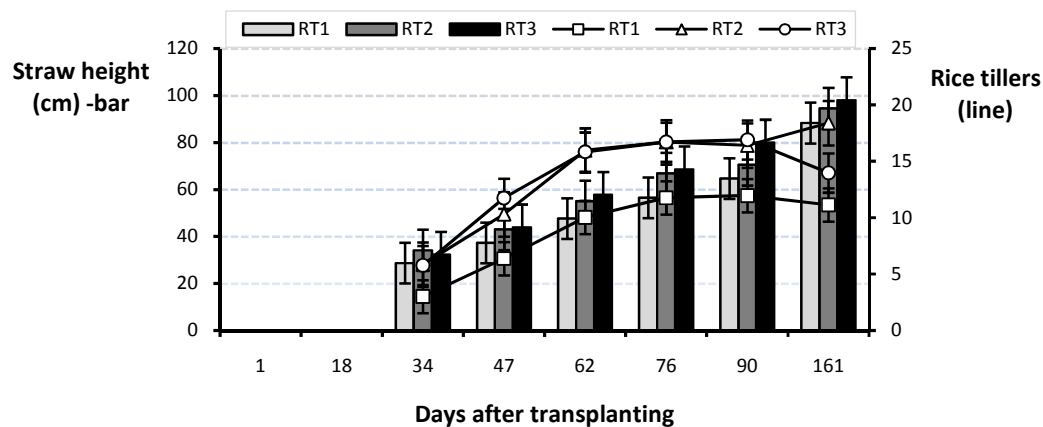


Figure 4.4. Rice tillering (lines) and straw height (bars) development after irrigating rice fields with water alone from canal (RT1), fertilisation with NPK & Urea (RT2), and with effluent from tilapia ponds (RT3).

The paddy yield in RT1 was not significantly different from that in RT2, but it was lower than the paddy yield in RT3 ($P < 0.05$). In these experimental conditions, the paddy yield ranged from 3.3 to 12.8 $t \cdot ha^{-1} \cdot crop^{-1}$. Table 4.3 summarizes the production performances of rice paddy and rice straw in $t \cdot ha^{-1} \cdot yr^{-1}$ as well as the quality of paddy grains based on the test weight, for example, weight of 1000 grains. No significant differences were detected among treatments in the weight of 1000 grains and in the net rice production. However, production in RT3 appeared to be slightly higher than in RT2 and in RT1.

Table 4.3. Rice growth and production parameters in rice fields fertilised by water from canal (RT1), inorganic fertilisers (RT2), and fish pond effluent (RT3)

Parameters	Unit	Treatments			
		RT1	RT2	RT3	<i>LSD</i> _{0.05}
#Paddy net yield (DW)	t.ha ⁻¹ .yr ⁻¹	13.3 ± 6.19	17.5 ± 2.65	22.4 ± 4.78	9.5 (NS)
#Paddy yield (DW)	t.ha ⁻¹ .crop ⁻¹	6.2 ± 2.90 ^a	8.2 ± 1.25 ^{ab}	10.6 ± 2.25 ^b	4.23 (*)
#Straw biomass (FW)	t.ha ⁻¹ .crop ⁻¹	30.9 ± 3.70	33.0 ± 3.9	40.4 ± 3.44	34.5 (NS)
Grain weight (10 ³ grains)	g	28.7 ± 0.58	29.7 ± 0.58	29.3 ± 1.35	1.2 (NS)
Missing plant at harvest		2.7 ± 1.15 ^a	9.0 ± 3.61 ^b	5.7 ± 0.58 ^{ab}	4.4 (*)

#The rice plot size was 6 m² and its yield was weighed after repeated sun-drying while the straw biomass was weighed fresh in the field at harvest time. Mean values with the same superscript letter within a row are not significantly different at the 0.05 level. **DW** and **FW** denote dry and fresh weights respectively.

4.3.4 Water quality in fishponds

Temperatures ranged between 20.6 and 22.9°C at dawn and increased from 24.8 to 29.9 °C in the afternoon, with mean temperature of 21.67°C at dawn, significantly lower ($P < 0.05$) than 26.20°C measured in the afternoon. A similar trend from morning to afternoon values was observed for dissolved oxygen (DO), which varied from 3.74 to 0.11 mg.l⁻¹ with a mean DO of 1.8 mg.l⁻¹ at dawn and 15.8 to 6.27 mg.l⁻¹ with a mean DO of 9.9 mg.l⁻¹ in the afternoon. Water pH remained in good range (6.5–8.4), but morning pH values were significantly lower than the afternoon ones. Additional water quality nutrients are indicated in Table 4. Chlorophyll *a* and total alkalinity values were in a good range for productive water. Mean concentration of chlorophyll *a* (21.06–77.84 µg.l⁻¹) generally increased over the experimental period in all treatments (Figure 4.5), and there were no significant differences among treatments. However, the two way ANOVA with treatment and time as factors showed a significant difference in time ($P < .001$), starting at day 63 (figure 4.6).

Except nitrates, for which treatments differed significantly ($P < 0.01$) in the gradient of stocking rates (PT1 showing lower nitrates than PT2 and the latter being lower than PT3) no significant differences were observed among treatments for all other nitrogen nutrients (total nitrogen, ammonia and nitrites) and none of them reached harmful values for Nile tilapia (Table 4.4).

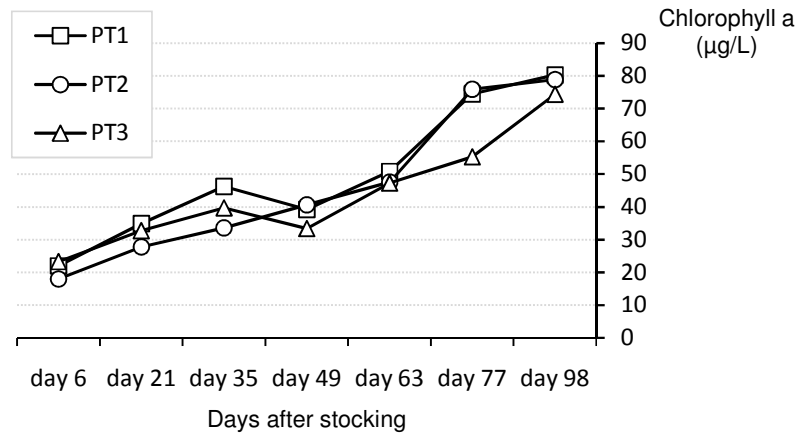


Figure 4.5. Changes in chlorophyll *a* in ponds stocked with 1, 2, and 3 males Nile tilapia per m² within an IRFR system

Concentrations of total phosphorus ranged from 0.02 to 0.23 mg.l⁻¹, considering all treatments, and no significant differences were found between treatments (Table 4.4). Soluble reactive phosphorus (SRP) were fish density dependent as highly stocked ponds (PT2 and PT3) were significantly more concentrated in phosphates than the treatment with one fish per m².

Table 4.4: Means with standard deviation for nutrients in pond water stocked with 1, 2, and 3 fish per m² (treatments PT1, PT2, PT3) and fertilised by rabbit droppings (dung and urine). Samples were a mixture of water collected at surface and bottom layers of the pond

Nutrients	Treatments			
	PT1	PT2	PT3	P _{0.05} & LSD _{0.05}
Chlorophyll a (µg.L ⁻¹)	49.670 ± 22.6	46.02 ± 23.4	43.73 ± 17.05 57.08 ± 7.50	NS
Total alkalinity (mgCaCO ₃ .L ⁻¹)	65.00 ± 15.6	66.33 ± 7.80	0.152 ± 0.12	NS
NH ₄ -N (mg.L ⁻¹)	0.237 ± 0.15	0.221 ± 0.19		NS
NO ₂ -N (mg.L ⁻¹)	0.034 ± 0.05	0.010 ± 0.01	0.063 ± 0.19	NS
NO ₃ -N (mg.L ⁻¹)	0.164 ± 0.10 ^a	0.194 ± 0.12 ^b	0.227 ± 0.13 ^c	(**) 0.013
TN (mg.L ⁻¹)	1.269 ± 0.30	1.335 ± 0.50	2.005 ± 0.17	NS
TP (mg.L ⁻¹)	0.113 ± 0.04	0.116 ± 0.05	0.100 ± 0.04	NS
SRP (mg.L ⁻¹)	1.138 ± 0.50 ^a	1.766 ± 0.77 ^b	1.562 ± 0.73 ^b	(**) 0.374

All data are means ± standard deviation of data collected on 3 replicates during the experimental period. Data that have same superscripts letters in the same row are not significantly different at P=0.05 (NS). (**): significantly different at P < 0.01.

4.3.5 Soil quality in fishpond and rice field

The soil pH did not differ among treatments (P>0.05), but it increased significantly over time both in tilapia ponds and in rice field for both treatments and over rearing time. Figure 4.6 shows changes that occurred in pond and rice field soil in all assessed nutrients. In fishpond soil, concentrations of total nitrogen, ammonia, ortho-phosphates, and total phosphorus were quite stable with ranges of 0.07–0.23 mg.l⁻¹, 6.0–20.2 mg.l⁻¹, 0.02–0.72 mg.l⁻¹, and 117.9–421.9 mg.l⁻¹ respectively, considering all treatments. In rice fields, a slight decrease but not significant (P>0.05) was observed in nitrogen from the start to the midterm in all treatments, however nitrogen increased slightly in both the treatments with NPK + Urea (0.135–0.170 mg.kg⁻¹) and more remarkably in the treatment with pond effluent (0.114–0.173 mg.kg⁻¹) from midterm to the end of the experiment.

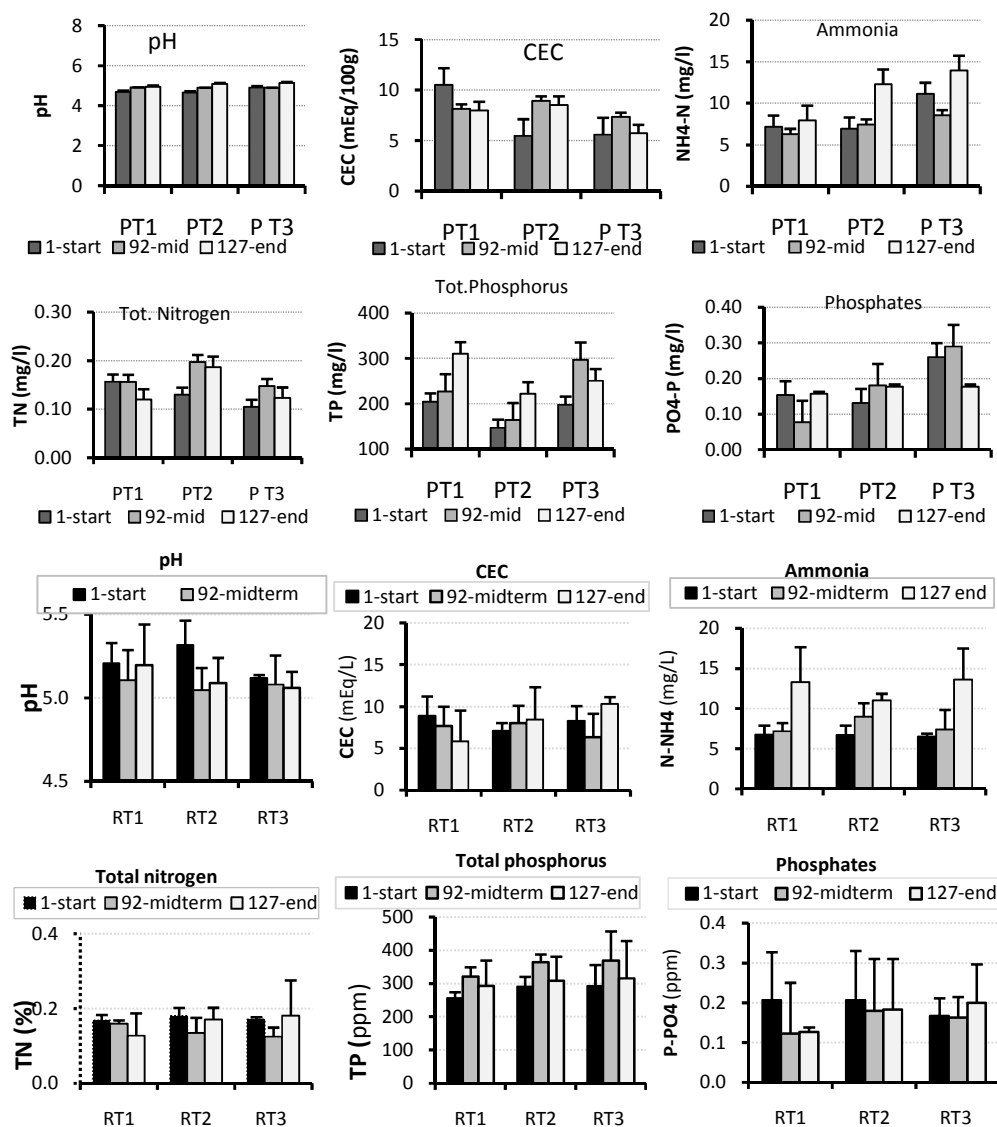


Figure 4.6. Changes in pH, and cations exchange capacity (CEC), and nutrient (total nitrogen (TN), ammonia, Phosphorus and ortho-phosphates). PT1, PT2, and PT3 are treatments with 1, 2, and 3 fish.m⁻²) applied on fish pond, and RT1, RT2, and RT3 are treatments applied on rice fields (fertilisation with water alone, inorganic fertilisers, and pond effluent); error bars are standard error of mean (n=9).

Contrarily, the total phosphorus did not increase statistically from the start to midterm but a trend of slight decrease from midterm to the end in all treatments was observed (Figure 4.6). The available phosphorus (phosphates) decreased from the start to midterm of the experiment, thereafter, augmented slightly towards the end in all treatments. Concerning the cation exchange capacity, no significant differences ($P>0.05$) were observed among treatments. Treatments with

fertilisation RT2 (NPK and urea) and RT3 (pond effluent) showed an increasing CEC towards the end (Figure 4.6) with the highest value in RT3.

4.4 Discussion

The overall analysis of the integrated rabbit–fish–rice system, in the current experiment, showed on-farm sources including rabbit droppings (urine and dung) and pond effluent being able to sustain sufficiently the system if well optimised. Similar observations have previously been made by other researchers (Prein, 2002; Xiuzhen, 2003; Nhan *et al.*, 2008) who stated that an increase in pond production depends on on-farm resources, mainly livestock wastes, plant remnants, and by-products. An appeal to off-farm sources such as manure, fish pellet feed and inorganic fertilisers would occur for medium and larger farming scale enterprises.

Various potential sources have been listed to improve farming activities. The effluent water from fishponds was the major on-farm nutrient source and accounted for 89% of the total N and 92.3% of the total P input. In IAA systems of the Mekong Delta, Vietnam, on-farm resources accounted for 32% of total N and 65% of all the phosphorus and carbon as many farmers supplement fish feeding with pellets, and orchid farms with inorganic fertilisers (Nhan *et al.*, 2008). Yi *et al.* (2006) found that effluent from hybrid catfish replaced completely the inorganic fertiliser in rice fields during an experiment in Vietnam, feeds accounting for up to 95.0% TN and 97% TP inputs. Inflow water in the present study, even though off-farm, accounted for the highest ratio in N and P nutrient inputs owing to the fact that the canal crossed through a cultivated valley upstream of the research site, thus receiving various inputs for vegetables and rice growth. Unlike this situation, most research done on the assessment of the impact of catfish pond effluent does not mention the inflow water as a potential source of nutrients (Boyd *et al.*, 2000; Yi *et al.*, 2006).

In the current study, irrigation water (effluent) was taken from a fertilised tilapia fishpond without any supplementary feed, but leading to a higher rice paddy production; this was not significantly different from that in rice fields receiving inorganic fertilisers but significantly different from rice fields irrigated by canal water without any fertiliser. Integrated pond systems and fishponds receiving fish feed are characterised by a high nutrient retention that results from

nutrient re-use by plankton and other microorganisms (Hopkins and Cruz, 1982; Edwards, 2004). For example, the pond wastes are constituted by nutrients and other organic materials resulting from fish feed after other nutrients have been adsorbed into pond sediment and only a small portion on inputs are recovered in fish, especially in tilapia ponds (Knud-Hansen *et al.*, 1998; Boyd and Queiroz, 2001; Boyd *et al.*, 2008).

These wastes are therefore potential sources likely to increase production of other fish and crops in integrated systems. Apart from canal water that filled the pond, rabbit droppings (urine and dung) were the most important source of nutrients for the ponds. Their processing by microorganisms into the pond provided nutrients and organic matter necessary for the development of plankton, the natural feed of Nile tilapia fish. Nutrients soluble in the water column and incorporated in plankton could flow and fertilise rice fields after others, such as ammonia, had been volatilized and most phosphorus adsorbed onto pond soil (Fernando and Halwart, 2000; Mohanty *et al.*, 2009).

Overall, fish growth performed poorly in this experiment, probably owing to the insufficiency of fertilising matter being provided by the rabbits stocked over the ponds. The study aimed at assessing the production that could be reached by the poor rural farmer, limited in land size and means of investment. Significant difference was then observed within the three treatments, constituted by one, two, and three fish per square meter of fish stocking rate.

The fish yield increased with increasing stocking rate. High stocking rates (2 and 3 fish.m⁻²) did not differ from one another for the harvested fish biomasses and the net fish production, but they were significantly higher than that achieved by the lowest stocking rate. In contrast, ponds with the lowest stocking rate showed significantly better performances in specific growth, daily weight gain, and the final mean weight of fish. The scarcity of published studies on fertilised tilapia ponds without supplemental feed prompted the comparison of observed performances with the effect of stocking density with Nile tilapia farmed either in polyculture or receiving supplemental feeding (Teichert-Coddington, 1996; Diana *et al.*, 1997; Long and Yi, 2004).

The dependency of fish yield and production on high stocking rate and vice versa for specific growth and daily weight gain have been discussed by various authors and in various farming

conditions (Diana *et al.*, 1997; Diana *et al.*, 2004; Long and Yi, 2004; Abou *et al.*, 2007). They all reported that fish mean weight at harvest decreased linearly or curvilinearly with increasing stocking rate and so did the trend for specific growth rate and daily weight gain while net and gross yield and production increased with increasing stocking density. According to Diana *et al.* (2004) the decrease of tilapia growth and survival rate with high stocking densities could be explained by tilapia behaviour or physiological response to density itself when water quality or any ecological threat is noted.

Considering that tilapia in all these experiments were fed complete feed or supplemented in fertilised ponds, the yields reported here (that is, 580, 900, and 1300 kg.ha⁻¹ for stocking rates of 1, 2, and 3 fish.m⁻² respectively) are reasonably acceptable as no feed was supplied and ponds were fertilised by a low density of rabbit (4 rabbits.are⁻¹, that is, 400 rabbits.ha⁻¹ of pond). Nevertheless, obtained growth and yields were comparable to that obtained in integrated tilapia–duck systems but far lower than yield from integration tilapia–pigs, and tilapia–chicken (Hopkins and Cruz, 1982).

Although most physical and chemical water quality parameters showed no significant differences among different fish stocking rates, they must signal a significant increase of soluble reactive phosphorus and nitrates with increasing fish stocking density. This must be associated with the importance of wastes released by fish biomass as no differences were detected among rabbit droppings per treatment. Higher concentrations of SRP and nitrates than these were recorded for tilapia ponds and / or tanks but were still density dependant (Breine *et al.*, 1996; Yi *et al.*, 1996; Long and Yi, 2004). The only difference was that ponds or tanks were fertilised. That must have increased the nutrients in the water, especially when they were not eaten.

Once the inflow water in ponds was enriched by the integrated aquaculture activity, the pond effluent became the major nutrient source for rice production. For normal rice farming, Rwandan rice farmers use inorganic and organic fertilisers (compost) and that is the case worldwide for attaining high yield (Gupta *et al.*, 1998; Vromant *et al.*, 2002a). The obtained paddy yields (8.312.2 t.ha⁻¹.crop⁻¹) in rice fields irrigated by fishpond effluent of the present experiment were higher than the average usually produced by local farmers under the supervision of the rice program of ISAR (3.5–6.0 t.ha⁻¹) for the *Yuni yin4* variety (Kayiranga, 2006).

Treatment with fishpond effluent (RT3) showed a higher yield, but not significantly, than that of the treatment with inorganic nutrient inputs but RT3 was significantly higher in yield than that obtained in treatment with water canal alone. This suggests that the effluent would have supplied more nutrients than that provided by the usual practice. Moreover, the rice and straw yield recorded during the current experiment showed that the *Yuni yin4* variety must have met its requirement for growth in the conditions of the experiment, contrary to observations made for the fish in ponds fertilised by 400 rabbits per hectare of pond.

Fish are reported to impact positively on rice yield by stirring up soil nutrients and making them more available for rice in direct rice-fish integration where fish also control insects and other competitors for material and energy (Mohanty *et al.*, 2009). In the present system, the role of fish would be limited to adding nutrient-rich waste to pond water and making available fertilising matter in the water column through their locomotive movement that stirs up the upper layer of bottom mud and diminishes the accumulation of all nutrients in sediment.

The origin of nutrients in pond bottom soil is basically from the organic, inorganic fertilisers and fish feed supplied to the fishponds. Even though this study used such a low stocking rate as the first source of nutrients in the integrated system, an increase in nutrient soil content over time was observed, especially for nitrogen nutrients between the start and the midterm of the experiment. This is mainly explained by the microbial activities of decomposition of wastes, organic matter from rabbit droppings and dead phytoplankton.

Various researchers concurred with the fact that a great portion of nutrients from feed, fertiliser and waste remain unused in ponds, thus settling out to the pond bottom (Knud-Hansen *et al.*, 1998; Lin and Yi, 2003; Rahman *et al.*, 2004). Avnimelech (1998) found that in carp ponds, only 25% of the feed nitrogen and 20% of phosphorus were recovered by fish and the rest accumulated in pond sediment. Nile tilapia recovered 12.75% N and 14.27% P of the waste in an integrated catfish–tilapia cage polyculture experiment (Yi and Lin, 2000b) while in a tilapia monoculture system, 18–21% of the applied N was accumulated in the fish and 79–82% discharged in the pond environment (Green *et al.*, 1995, in Rahman *et al.*, 2004).

These findings imply that the improvement in pond soil nutrients, even though low, finds its origin in the rabbit droppings. It is generally agreed that pond sediment is a potential source of pollution if not managed judiciously (Foy et al, 1987, in [Rahman et al., 2004](#)). To avoid or reduce the threat of environmental pollution, the nutrients and organic matter should be utilised in economic activities such as in agriculture productions (crops, nurseries, horticultural activities).

The present study tested the use of pond water collected from the bottom of the ponds to fertilise rice fields. The experiment demonstrated that apart from contributing towards high rice production, the effluent increased the nutrient content of the rice field soil, especially in nitrogen, ammonia-nitrogen and in available phosphorus. An increase in the rabbit stocking rate could provide highly nutrient-rich water, capable of replacing totally inorganic fertiliser in irrigated rice.

4.5 Conclusions

The investigation of the functionality of resources (actual and potential) in the integrated rabbit–fish–rice system identified two main scenarios to be applied: one relies on on-farm materials with only the inflow water as an off-farm source of nutrients; and the second combining on-farm and off-farm products as the main sources of nutrients.

Rabbit droppings (urine and excrement) for fishponds and pond effluent water for rice fields accounted for 89% of the total nitrogen and 92.3% of the total phosphorus input in rice fields. The rabbit–fish–rice integration results in the production of on-farm nutrient resources such as livestock manure, plant remnants, and compost. The effluent from Nile tilapia ponds can completely replace the NPK and urea applied in the treatment RT2 of the experiment. The study pointed out the need to increase the stocking rate in rabbits so as to increase fish production and nutrients for other integrated agriculture on pond dyke and/or downstream for irrigated rice. Consequently, quantities of accumulated nutrients in pond bottom soil as well as in discharged water will augment. This finding urges farmers to undertake better management practices for ponds and better use of effluent in order to sustain production and enhance the profitability while protecting the environment. The increase of rabbit density over fishponds should however have a

limit to maintain an ecological equilibrium in the pond and avoid eventual pollution. This requires specific investigations to prepare guide lines for rural farmers intending to apply the IAA system in their farming activities. Production of rabbits, rice paddy, and Nile tilapia remain quite promising.

Results from this study prompt a need to further investigate the re-use of tilapia pond effluent and other resources of the integrated system. This includes the optimum number and biomass of livestock source of nutrients, the maximisation of production by exploiting all potential levels of the integration, and studies on economics of various integration scenarios, including polyculture in ponds, various responses from different agricultural crops, as well as supplemental feeding for both fish and rabbits.

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5. CHAPTER FIVE: Optimum Rabbit Density over Fish Ponds to Optimise Nile Tilapia Production in an Integrated Rabbit–Fish System in Rwanda

The following paper was written based on this chapter:

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Abstract

Although studies have proved rabbit excreta to be high quality manure for sustaining plankton production, due to gradual nutrient release, rabbit–fish integrated production systems are still not widespread. The present study focused on optimising rabbit densities for sustainable rabbit–fish integrated farming. The study aimed at assessing the effects of various rabbit densities on plankton type and abundance, fish production, and water quality change of the fish culture environment. Two hundred, four hundred, eight hundred, twelve hundred, and sixteen hundred rabbits per hectare of pond were reared between 2006 and 2010 over ponds in replicates. Water physico-chemical parameters, plankton, and fish performance were monitored on a daily and/or bi-weekly basis.

Fish yield was dependent on rabbit density but with a density of greater than 1200 rabbits.ha⁻¹ of pond, the yield began decreasing with increasing inorganic nitrogen (especially ammonia) and decreasing oxygen. Phytoplankton biomass based on chlorophyll *a* increased with increasing rabbit densities and so did daily primary productivity. From this study, it appears that the optimum density could only be included in the range of 800 to 1200 rabbits.ha⁻¹ of pond. This range showed that it was difficult to arrive at a conclusion based on a single rabbit density as key parameters did not simultaneously reach their best level. The density of 800 to 1200 rabbits.ha⁻¹ of pond appeared to be the optimum density as it showed the highest fish yield (2.4–3.3 t.ha⁻¹.yr⁻¹), the best growth rates, and the best environment for plankton.

Keywords: water quality, fish performance, rabbit density, optimisation, plankton type, and abundance.

5.1 Introduction

Pressure on natural resources is becoming increasingly evident in countries that are experiencing high population growth, such as Rwanda. This pressure leads to land degradation and environmental damage in general and consequently poverty and food insecurity. According to [Pretty *et al.* \(2003\)](#), the causes of low agricultural production in Africa are widespread stagnation of the general economy, persistence of political instability and increasing environmental damage. Aquaculture integrated with other forms of agricultural production, is known to be one of the means that can efficiently alleviate the problem by increasing food production.

Fish is important to food security and nutrition, especially in low-income countries, where it provides 20.1% of the total animal protein intake ([FAO, 2010](#)). In West Africa, fish is even more important. In this region, the proportion of fish-derived dietary protein ranges between 47% and 63% ([FAO, 2006](#)). Capture fisheries and aquaculture production is perceived as the fastest growing food-producing sector and is now a worldwide phenomenon with an overall production estimated to be 142.3 million tonnes in 2008. On the whole, 62.3% of world aquaculture production is from China, while sub-Saharan countries contribute only 0.5% ([FAO, 2010](#)). In large parts of Asia, including China, aquaculture is a traditional practice so as even poor aquaculturists farm fish with confidence for the applied production technology, whereas in sub-Saharan Africa, aquaculture seems unpopular.

The poor contribution made by aquaculture in this part of Africa arises from the fact that fish farming is not part of the population's traditional agricultural practice, and most fish farmers in Rwanda, for example, lack basic knowledge in aquaculture techniques. [Karamaga and Mpawenayo \(1991\)](#) reported that Rwandan rural farmers have not been enthusiastic about fish farming and manifest a low enthusiasm for fish meal since the introduction of aquaculture during the 1950s. Despite the fact that aquaculture is recognized as an important livelihood asset in many countries, it can also lead to negative impacts on the environment and human communities if the required appropriate management practices are not carried out. Intensive aquaculture relies on mostly natural resources such as land and water, seed and feed, and energy (e.g; petroleum-based fuels and electricity), the use of which requires competent and sustainable management in order to avoid problems with environmental pollution, human health, and food safety.

Farmers on a small scale in developing countries cannot afford the energy costs of a successful aquaculture enterprise that is environmentally friendly and that uses a water recirculation system. [Troell *et al.* \(2004\)](#) indicate that optimisation procedures were the best approach to address the problem of energy cost for aquaculture within an ecosystem and they recommended that optimization be adopted at all aquaculture production scales, with organized training for small farmers. In addition, experience from the Asian fish farming industry and research by [Little and Edwards \(2003\)](#) and [Hopkins and Cruz \(1982\)](#) indicated that better fish production was obtained after animal husbandry was integrated with fish culture.

Fish have been raised in ponds fertilised by chickens, ducks and pigs; maintaining good water quality and better tilapia production in the Philippines, Thailand, Vietnam, and Cambodia. Animal manure is used as organic fertiliser, providing nutrients for aquaculture ponds to stimulate primary production and offering the possibility of increasing natural food availability for fish and of course, overall pond productivity ([Knud-Hansen and Batterson, 1994](#); [Kumar and Ayyapan, 1998](#); [Azim *et al.*, 2001](#); [Diana *et al.*, 2004](#)). The use of animal manure for fishpond fertilisation requires great care from the farmer who must respect fertilisation rates and application frequency, especially for ponds that lack regular water flow, such as finger ponds and some earthen ponds ([Garg and Bhatnagar, 2000](#); [Kipkemboi, 2006](#)).

Trials of integrating the farming of various animals were conducted in Rwanda, but research into the impact of fish culture integrated with animal husbandry, on water and pond soil ecology and fish productivity, was still limited to different types of manure, namely that of chickens, ducks, pigs, goats, grass compost and other by-products from plants growing on pond dikes ([Veverica *et al.*, 1999](#)). Rabbits were observed only for their potential in enhancing fish production ([Van Vleet, 1997](#)).

In the rural regions of Rwanda, direct integration of aquaculture and animal husbandry is still not yet common, mainly due to a lack of sufficient knowledge in aquaculture and integrated aquaculture. Cowsheds, henhouses and rabbit hutches are kept in homesteads, whereas herbivores (cattle, sheep and goats) graze freely in the fields, whereas rabbits and poultry are fed in households. Thus, fishponds established in remote areas are likely to get fewer inputs than those close to homestead gardens ([Verheust *et al.*, 1995](#)).

The problem of the shortage of organic inputs for fishponds can be solved only through adoption of Integrated Agriculture Aquaculture (IAA) systems, which involves the direct use of agricultural wastes (especially from livestock) as well as the recycling of manure-based nutrients that work as fertilisers to stimulate the natural food web in water (Little and Edwards, 2003). In the current study, rabbit excreta (faeces and urine) are recycled into ponds' inputs which fertilise pond water which consequently becomes enriched with phytoplankton and zooplankton. The latter serves as food for filter-feeder fish such as Nile tilapia, reducing the expenses of artificial food, especially for resource-poor farmers. The enterprise also appears environmentally friendly as it prevents environmental pollution by agricultural wastes. The pond water got then fertilised and likely to serve successfully in the irrigation of crops farmed on pond dykes.

Research conducted at the National University of Rwanda focused on adapting rabbits to wetland conditions, integrating rabbit and fish production and trying to develop knowledge-based IAA systems that could be easily applicable by rural farmers. Initial research, which evaluated the impact of rabbit droppings from on-farm sources (IAA systems) and rabbit manure produced off-farm as organic fertiliser for ponds, revealed better growth rates for both rabbits and fish, and better fish production: 970 and 810 kg.ha⁻¹.yr⁻¹ respectively for an IAA system and pond fertilisation by off-farm sourced manure (Rukera Tabaro, 2001).

Recently, an investigation oriented to the effects of rabbit droppings on fishpond sediment and water quality and to the improvement of Nile tilapia production in IAA systems, revealed a better environment for fish growth in all ponds and better net fish yield (1840 kg.ha⁻¹.yr⁻¹) in ponds that received droppings from the largest number of rabbits (400 rabbits.ha⁻¹ of pond) housed over ponds and with no reduction in water quality (chapter 3). The observation prompted further research to establish what the optimal number of rabbits could be to provide organic inputs in a sustainable manner.

The objectives of this chapter were to determine pond water quality, phytoplankton abundance, and assess fish growth and fish production in ponds fertilised by various rabbit densities in order to assess the optimal density. The research intends to provide practical measures, to be applied by fish farmers in rural areas, in order to achieve better production levels with low input costs.

5.2 Materials and Methods

5.2.1 Study site and experimental set up

Experiments were conducted separately with various objectives, for a period of approximately 4 months, using 9 earthen ponds of 0.04 ha surface area each at the Rwasave Fish Farming Research Station (geographic coordinates: 2°40'S and 29°45'E), National University of Rwanda, Butare, Rwanda (Figure 3.2). Ponds were first drained twice and dredged to avoid any influence (especially pH and alkalinity as well as nutrients) from mud contaminated by nutrients from previous fish culture experiments. The ponds were thereafter filled with water from the river Rwabuye which supplies the whole marsh of Rwasave. Further water was added only to compensate for losses from evaporation, seepage and occasionally, rice irrigation. Trials using various rabbit densities were conducted over three different periods in rectangular earthen ponds with 0.04 ha (400 m²) surface area and an average depth of 1 m. The first experiment in 2005 aimed at assessing the water quality change and fish growth in ponds fertilised by 400, 800 and 1600 rabbits.ha⁻¹ each density replicated in three ponds.

The second experiment in 2008 used all nine ponds (0.04ha x 1m) using 100, 200 and 400 rabbits.ha⁻¹ of pond and aimed at assessing water quality change and fish growth in an extensive system and the third experiment was conducted in six ponds. Two treatments made of 1 and 2 fingerlings.m⁻² were assigned randomly to six ponds. Every pond was fertilised by 1200 rabbits.ha⁻¹ of pond. Each experiment used rabbits about 1 or 2 weeks post -weaning (600–800 g mean live weight), which were fed on grass and supplied with drinking water from a spring.

The present study was conducted over the experimented rabbit densities named T2, T4, T8, T12, and T16 constituted by 200, 400, 800, 1200 and 1600 rabbits.ha⁻¹ of pond, respectively, to determine optimization of rabbit density. The rabbits were all fed on grass, were almost all of the same age and acted on the same species of fish (Nile tilapia). Dung and urine were collected fortnightly throughout a 24 hour cycle, from a cage of 2 or 4 rabbits depending on the treatment and amounts were extrapolated to calculate the amount of droppings discharged into ponds on a daily basis. All treatments were compared to one another and no control was set.

After the experiments, raw data chosen from treatments with 200, 400, 800, 1200, and 1600 rabbits.ha⁻¹ of pond which were stocked with 2 fingerlings per m² and distributed into 3 ponds as replicates were assembled for analysis. These five different rabbit densities were investigated for their effect on water quality change, plankton production, plankton type and abundance in water and the consequent growth and production of Nile tilapia. For each experiment, rabbit live-weights were recorded fortnightly to assess rabbits' growth when hatched over fishponds and dead rabbits were weighed, recorded and replaced to ensure the density remained stable during the experiment. The variation in replaced biomass was however unavoidable.

5.2.2 Physico-chemical parameters

Dissolved oxygen (DO), pH, electrical conductivity at 25 °C, and Secchi disk visibility were measured directly *in situ*, whereas nutrients (nitrogen and phosphorus forms) were analysed from a water sample collected fortnightly using the Van Dorn bottle; a sampler that allows one to collect water from the surface, middle and bottom of the pond. The three sub-samples were mixed in a bucket from which one litre of water was kept for laboratory analysis. After filtration through a Whatman filter, total ammonia (NH₄-N) and nitrates (NO₃-N) were analysed by the colorimetric method (Boyd, 1979), nitrite (NO₂-N) by standard methods (APHA, 1985) and ortho-phosphates (soluble reactive phosphorus) by the ascorbic acid method (Descy, 1989). A crude water sample was used to analyse total nitrogen (TKN) by the Kjeldahl method (APHA, 1985) and total phosphorus (TP) was determined by persulfate digestion (Boyd, 1979). Water temperature and dissolved oxygen (WTW oxi 325/set), pH (WTW pH320/set 2) and conductivity at 25°C (WTW LF 38/set) were measured every two weeks, between 07h00 and 08h00 am, directly in ponds and water transparency in cm (Secchi disk) measurements were recorded between 11h00 and 12h00 during the period of high sunshine.

5.2.3 Phytoplankton composition, abundance, and pond primary productivity

Water samples were taken once per month at five depths (20, 40, 60, 80 and 100 cm) using the Van Dorn water sampler and mixed in a bucket per fishpond. A one litre sub-sample was collected, fixed with Lugol 10% and concentrated into 10 ml after sedimentation. Phytoplankton

taxa were identified using identification keys (Bourelly, 1968, 1970; Iltis and Compère, 1974; Compère, 1975, 1976; Bourelly, 1981; Compère, 1992) and counted using the Burker-Türk cell counting chamber under a microscope (Leitz) at 100X and 400X magnifications. The Burker-Türk cell contains 4 groups of 16 squares ($0.0025\text{mm}^2 \times 0.10\text{mm}$ depth). The plankton counting was, therefore, done in 25.10^{-5}mm^3 sample volumes. The counting was repeated 2 to 3 times until the same number was repeated thrice and no new species observed. Relative abundance was obtained by the following formula

$$Ar = N_x / N_t * 100 \quad \text{where} \quad Ar = \text{relative abundance in \%}$$

$$N_x = \text{absolute number of taxa "x" (Number/ml)}$$

$$N_t = \text{total number of taxa observed in 2 to 3 cells}$$

Zooplankton samples were collected by filtering 10 litres of pond water taken at different locations at depths between 20 and 100 cm and filtered through $63\mu\text{m}$ plankton net. The concentrated samples were fixed with 4% formalin and identified and counted using an inverted microscope Leica DMIL. Zooplankton were identified using identification keys (Dussart, 1969; Pontin, 1978; Amoros, 1984; Pourriot and Francez, 1986).

Fishpond primary productivity was determined through measurement of dissolved oxygen using an oxymeter and the Winkler method (Descy, 1989). The light and dark bottle method (Boyd, 1979; Descy, 1989) was used and oxygen concentration was measured at different depths. Produced oxygen and consumed oxygen by respiration were recorded after 4 hours incubation to calculate pond net and gross productivity. Daily productivity was determined using the photosynthesis simulator PSS2000®, version 2.1 (Dauta and Capblancq, 1999). The pond primary production was also assessed through determination of Chlorophyll *a* by the Pecchar method adapted by Léonard and Kanangire (1998).

5.2.4 Fish growth and production

Individual fish biomass was measured using an electronic balance (Mettler balance, accuracy: 0.1g) on a sample of 35 fish per pond taken every 2 weeks and the fish were returned

immediately to their corresponding ponds. After a culture period of approximately four months after stocking, ponds were completely drained and the fish were harvested and counted and their total biomass was recorded after individually weighing the sample to the nearest gram. Fish data at stocking and harvest were used to calculate: the survival rate (SR: %), the specific growth rate as a percentage per day (%.day⁻¹) ($SGR = [(\ln W_t - \ln W_o) \times 100 \text{ t}^{-1}]$ where W_o and W_t are the body weight (g) at stocking and harvest respectively and t is time in days (d); the daily weight gain (DWG) in gram per day (g.day⁻¹) = $[(W_t - W_o) / (t_1 - t_o)]$; and fish production as net fish yield (NFY) expressed in kilogram of fish per hectare per year (kg.ha⁻¹.yr⁻¹) [equals total biomass of fish at harvest minus total biomass of fish at stocking] according to the fishpond size and over a one year period (Azim *et al.*, 2002).

5.2.5 Optimum density determination

The measurements of the daily rabbit droppings through a 24 hour cycle, the data from water quality monitoring and plankton abundance in water and the fish yields and growth parameters were all used to decide on the optimal rabbit density. The density that induced the maximum fish yield, the best growth rates (DWG and SGR), the highest abundance of phytoplankton and the best environment for fish (water quality) should be considered as the optimum rabbit density.

5.2.6 Statistical analysis

All data were encoded into tables in Microsoft Excel worksheets which were imported by GenStat 12th edition statistical software and used to perform the statistical analysis. The assumptions of normal distributions and homogeneity of variances were checked before analysis. Physico-chemical parameters that were monitored over time were analysed using ANOVA of repeated measurements, performed by Genstat 12th edition. The software was then run to get output from ANOVA of repeated measurements, with rabbit densities as treatments and culture time, the main factors in determining water quality parameters. For fish growth parameters such as SGR, DWG and survival, one-way ANOVA was used. The least significant differences of means (LSD, 5% level) were used to compare treatments in case significant differences were observed with ANOVA. Correlation and multiple linear regression analysis were used to assess

possible relationships between rabbit density as response variate fish yield and growth parameters, as well as with some physico-chemical and biological parameters as explanatory variates.

5.3 Results

5.3.1 Effect of rabbit density on the evolution of water quality in fishponds

Data for DO and pH are shown in Table 5.1 and include minimum, maximum and mean values. The larger the number of rabbits, the lower the concentration of mean oxygen in the ponds. DO at dawn varied between 0.06 and 6.51 mg.l⁻¹ in all treatments and stressful concentrations of DO were observed in T8, T12 and T16, while T2 and T4 had a mean DO above 4 mg.l⁻¹. pH, in all treatments, varied between 5.4 and 7.4, with a mean pH of between 6.7 and 6.9 (Table 5.1) without any significant difference among treatments. Inorganic nitrogen usually accumulates when manuring ponds (Van Rijn, 1997). Mean values of NH₄-N varied between 0.48 and 1.12 mg.l⁻¹ for all treatments but no harmful effects were observed. High concentrations were noted from those treatments with higher loads of rabbits (Figure 5.1) except T12. Nitrites-nitrogen (NO₂-N) concentrations were in a good range for fish life in all treatments (0.3 to 1.05 mg.l⁻¹), and the highest mean value was observed in T12.

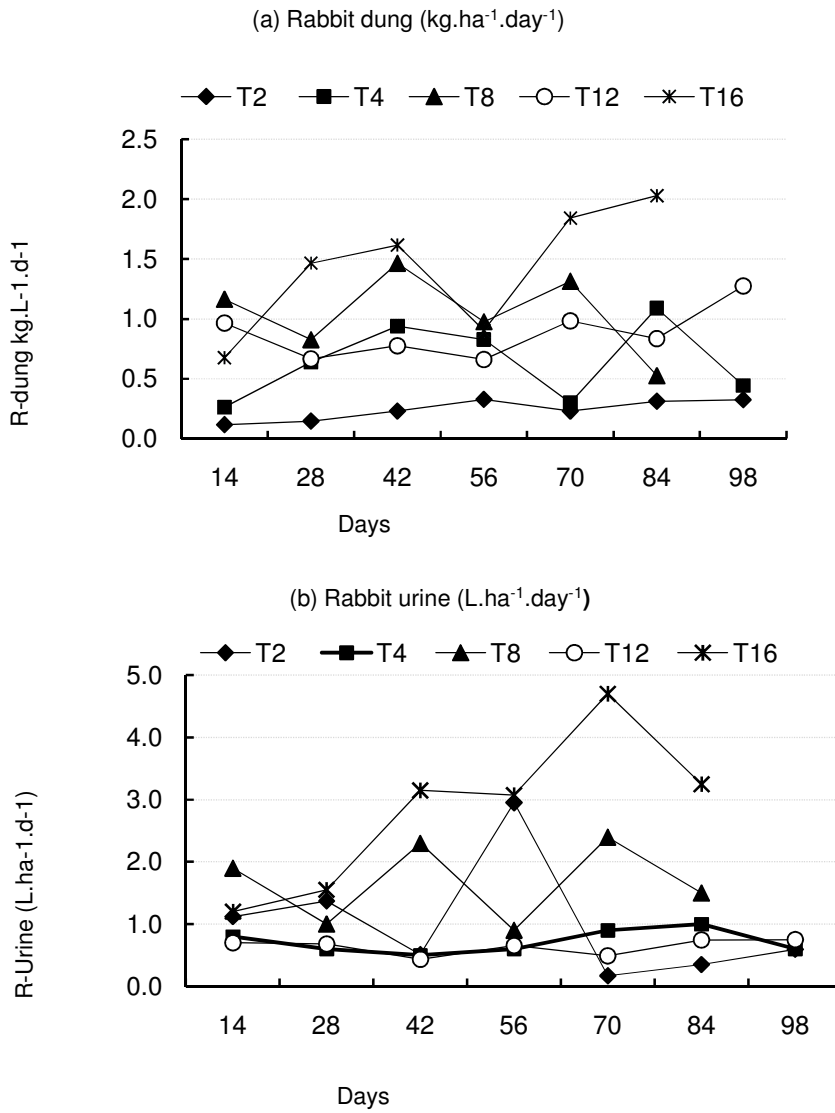


Figure 5.1: Rabbits droppings: (a) dung ($\text{kgDM} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$) and (b) urine ($\text{L} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$) discharged daily into fish ponds stocked with $2 \text{ fish} \cdot \text{m}^{-2}$ for five treatments (T2: $200 \text{ rabbits} \cdot \text{ha}^{-1}$, T4: $400 \text{ rabbits} \cdot \text{ha}^{-1}$, T8: $800 \text{ rabbits} \cdot \text{ha}^{-1}$, T12: $1200 \text{ rabbits} \cdot \text{ha}^{-1}$, and T16: $1600 \text{ rabbits} \cdot \text{ha}^{-1}$ of pond. ($\text{kgDM} \cdot \text{ha}^{-1} \cdot \text{day}^{-1}$: kg of dry matter per ha per day).

Table 5.1: Physico-chemistry change in water fertilised by rabbit droppings from five different rabbit densities housed over fish ponds: T2: 200 rabbits.ha-1, T4: 400 rabbits.ha-1, T8: 800 rabbits.ha-1, T12: 1200 rabbits.ha-1, T16: 1600 rabbits.ha-1 of pond

Parameters/ Treatments	T2	T4	T8	T12	T16	LSD _{0.05}
Water transparency (cm)	32.5 ± 5.8 ^a (22 – 43.5)	32.8 ± 3.5 ^a (28 – 41)	28.7 ± 5.7 ^b (19-51)	26.6 ± 4.3 ^b (18 – 35.5)	19.0 ± 6.8 ^c (14-47)	3.50 *
Temperature (°C)	23.7 ± 2.4 ^a (19.13 – 27.57)	20.5 ± 0.8 ^a (17.80 – 20.10)	20.5 ± 1.3 ^a (18.8-22.9)	21.8 ± 0.7 ^a (20.80 – 22.90)	20.6 ± 1.6 ^a (18.7-23.3)	3.37 ns
Dissolved Oxygen (mg.l⁻¹)	4.6 ± 1.4 ^a (1.98 – 6.51)	4.9 ± 1.3 ^a (1.66 – 6.48)	1.7 ± 1.7 ^b (0.06-5.47)	1.7 ± 1.2 ^b (0.11 – 3.74)	1.3 ± 1.8 ^b (0.06-5.48)	1.08 *
pH	6.9 ± 0.2 ^a (6.51 – 7.20)	6.9 ± 0.1 ^a (6.63 – 7.11)	6.7 ± 0.3 ^b (6.24-7.1)	6.9 ± 0.1 ^a (6.54 – 7.10)	6.7 ± 0.4 ^b (5.41-7.44)	0.15 *
Total Nitrogen (mg.l⁻¹)	4.7 ± 1.5 ^a (1.26 – 9.52)	5.4 ± 2.3 ^{ab} (1.26 – 9.52)	6.1 ± 1.9 ^{ab} (3.1-11.2)	6.9 ± 1.2 ^b (1.3 – 16.4)	6.2 ± 1.9 ^{ab} (3.3-11.0)	1.84 **
Ammonia (mg.l⁻¹)	0.5 ± 0.4 ^a (0.07- 1.47)	0.7 ± 0.3 ^a (0.21 – 1.47)	1.0 ± 0.4 ^b (0 - 1.8)	0.5 ± 0.4 ^a (0.09 – 1.54)	1.1 ± 0.6 ^b (0.2 - 2.7)	0.48 *
Nitrites (mg.l⁻¹)	0.3 ± 0.3 ^a (0.04 – 0.71)	0.7 ± 0.5 ^a (0.12 – 1.77)	0.3 ± 0.3 ^a (0.05-1.45)	1.1 ± 0.7 ^b (0.18 – 1.76)	0.3 ± 0.3 ^a (0.05-1.33)	0.49*
Nitrates (mg.l⁻¹)	2.8 ± 2.0 ^a (0.26 – 7.84)	3.0 ± 2.93 ^a (0.68 - 11.96)	2.1 ± 1.2 ^a (0.16-6.42)	2.9 ± 2.0 ^a (0.56 – 9.40)	2.4 ± 1.4 ^a (0.49-9.72)	3.28 *
Total Phosphorus (mg.l⁻¹)	0.5 ± 0.3 ^a (0.06 – 1.25)	0.8 ± 0.5 ^a (0.12 – 1.74)	0.6 ± 0.4 ^a (0.11-1.68)	0.6 ± 0.5 ^a (0.1 – 1.9)	0.6 ± 0.4 ^a (0.14-1.30)	0.36 ns
Ortho-phosphates (mg.l⁻¹)	0.1 ± 0.04 ^a (0.01 – 0.17)	0.1 ± 0.1 ^a (0.048 – 0.285)	0.1 ± 0.1 ^a (0.05-0.28)	0.3 ± 0.26 ^b (0.002 - 0.865)	0.1 ± 0.12 ^a (0 – 0.47)	0.15 **
Chlorophyll a (µg.l⁻¹)	44.8 ± 20.7 ^a (17.35 – 97.59)	45.8 ± 22.3 ^a (18.51 – 110.61)	57.9 ± 52.6 ^a (2.67-179.09)	71.5 ± 42.7 ^{ab} (20.39 – 199.16)	93.0 ± 77.8 ^b (2.67 – 272.65)	31.17

Values are mean ±SD from three replicates and eight sampling dates (n = 24). Figures in parenthesis are minimum and maximum values for each parameter. Values with same superscript letters are not significantly different (P<0.05). LSD (5% level): Least Significant Difference obtained by Analysis of variance for repeated measurements and used to separate different means.

Nitrates ($\text{NO}_3\text{-N}$) varied between 0.2 and 12.0 mg.l^{-1} in ponds, considering all treatments and mean values did not reach 6.0 mg.l^{-1} $\text{NO}_3\text{-N}$ (Figure 5.1). However, no significant differences in nitrate concentrations were observed among treatments.

Phosphorus was analysed in two forms. Total phosphorus and Ortho-phosphates were analysed and were found to be highly concentrated in treatments T8, T12 and T16. On the other hand, values for ortho-phosphates varied between 0.01 and 0.9 mg.l^{-1} in all treatments, mean values being situated between 0.1 mg.l^{-1} and 0.3 mg.l^{-1} and between 0.5 mg.l^{-1} and 0.8 mg.l^{-1} for total phosphorus. Ortho-phosphate concentrations were significantly higher ($P < .001$) in T12 than in the other three lower densities (T2, T4, T8 and T16).

5.3.2 Plankton composition and abundance

Figures 5.2 and 5.3 show the main plankton groups and their relative abundance observed in ponds after fertilisation with different rabbit densities. The phytoplankton community appeared to be dominated by *Euglenophyceae* (mostly represented by genera *Trachelomonas*, *Euglena* and *Phacus*) followed by *Chlorophyceae*. The *Euglenophyceae* was mostly located in ponds with higher rabbit densities, T8 and T16, whilst *Chlorophyceae* and *Cyanophyceae* were more highly concentrated in ponds with smaller rabbit densities (T2 and T4) than in T8 and T16 (Figure 5.2).

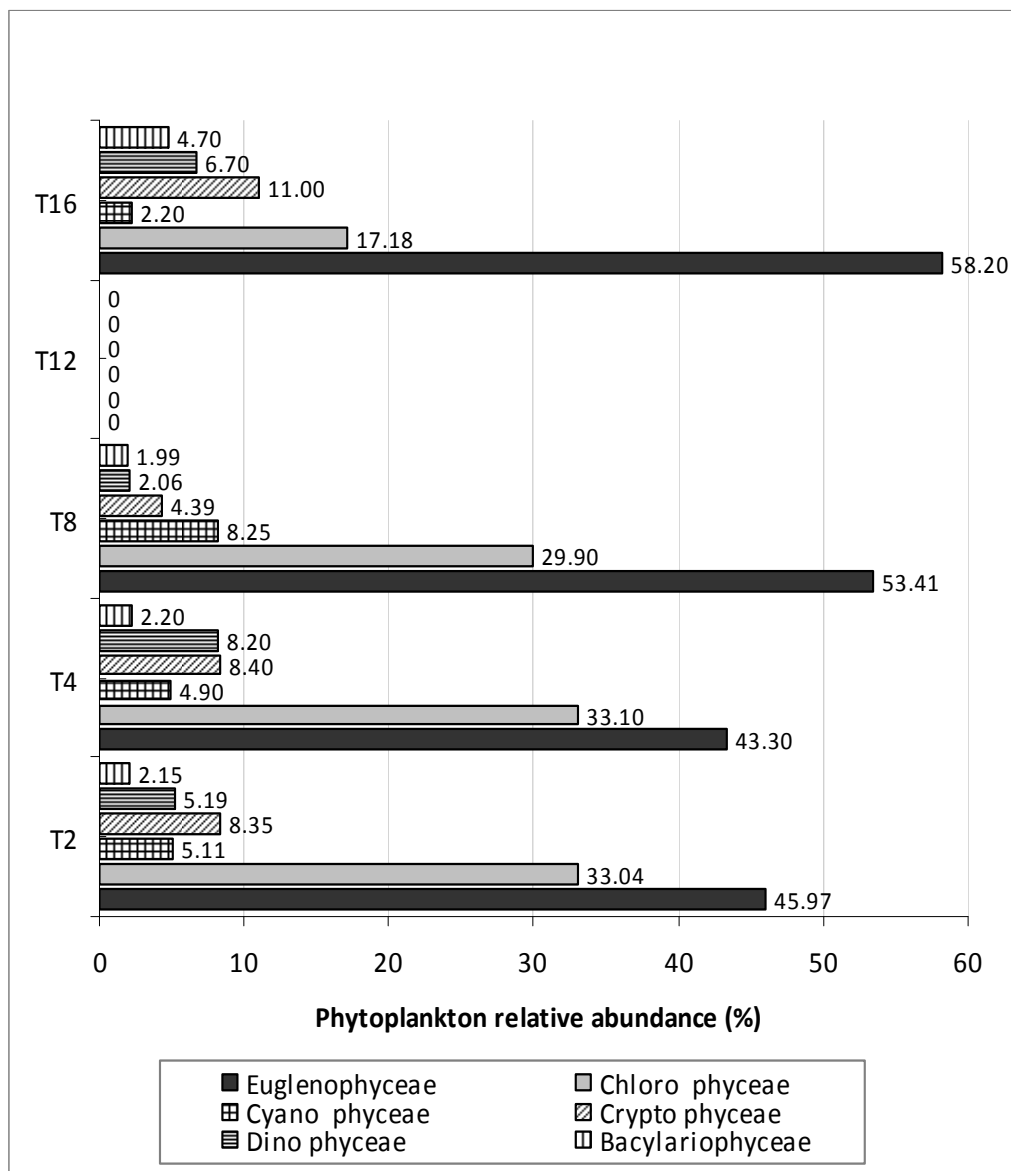


Figure 5.2: Phytoplankton abundance as a percentage of main group taxa in fish ponds fertilised by rabbit droppings from different rabbit loads over ponds (T2: 200 rabbits.ha⁻¹, T4: 400 rabbits.ha⁻¹, T8: 800 rabbits.ha⁻¹, T12: 1200 rabbits.ha⁻¹, and T16: 1600 rabbits.ha⁻¹). No data were collected on plankton in trials using 1200 rabbits per hectare of pond.

Similar observation was true for *Rotifera* in the zooplankton group. They were mostly recorded in ponds receiving droppings from high rabbit densities (T8 and T16) followed by *Copepoda*, a crustacean which was relatively more highly represented in ponds receiving droppings from

lower rabbit densities (T2 and T4). *Cladocera* was the crustacean group least represented of all the zooplankton (Figure 5.3).

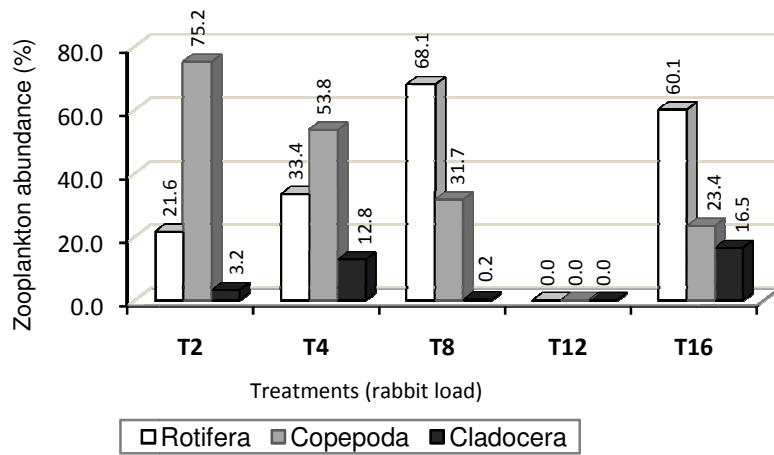


Figure 5.3: Main group taxa of zooplankton and their abundances (%) in fish ponds fertilised by rabbit droppings from different rabbit densities over fish ponds (T2: 200 rabbits.ha⁻¹, T4: 400 rabbits.ha⁻¹, T8: 800 rabbits.ha⁻¹, T12: 1200 rabbits.ha⁻¹, and T16: 1600 rabbits.ha⁻¹) in an Integrated rabbit–fish–rice system.

5.3.3 Water transparency, Chlorophyll *a* and daily primary productivity

The Secchi visibility varied between 14 cm and 51 cm as extreme limits in pond water transparency. The lowest visibility showing eutrophication was observed in T16 where the mean secchi visibility was 19 cm (Table 5.1), whilst other treatments were above 25 cm of water transparency.

Chlorophyll *a* was significantly affected by sampling time ($P < 0.001$) and rabbit densities and the highest values were observed during week 12 and week 14 by the end of experiment. Chlorophyll *a* concentration was directly linked to rabbit density and the highest concentration was observed in T16 which was significantly higher ($P < 0.05$) than all other rabbit densities. This was followed by T12 which was not much different from T16, while mean chlorophyll *a* values for all treatments varied between 45 and 93 $\mu\text{g.l}^{-1}$ (Table 5.1). Daily primary productivity (DPP) varied between 0.15 and 1.86 $\text{gC.m}^{-2}.\text{day}^{-1}$.

The DPP value for T12 was significantly higher ($P < 0.05$) than all other treatments, indicating a maximum phytoplankton productivity that was expected in T12 considering its Chlorophyll *a* concentration.

5.3.4 Growth and production of Nile tilapia in ponds

Growth performance of Nile tilapia, harvested in ponds fertilised with rabbit droppings from different rabbit densities are given in Table 5.2. The best tilapia growth was observed in ponds which received droppings from 12 rabbits per area of pond. Treatment T12 showed a daily weight gain (DWG: $0.3 \text{ g.fish}^{-1}.\text{day}^{-1}$) and net fish yield (NFY: $3256 \text{ kg.ha}^{-1}.\text{yr}^{-1}$) both significantly different ($P < 0.05$) from all other treatments at harvest. Tilapia survival rates were significantly lower in T16 than in the other four treatments, among which survival rates were not significantly different. Tilapia were characterised by a very low daily weight gain in all treatments but the best DWG (Table 5.2) was recorded in ponds receiving droppings from high rabbit densities (T8, T12, and T16).

Table 5.2: Growth and production performances of Nile tilapia in fish ponds fertilised by five different stocking loads (T2: 200 rabbits.ha⁻¹, T4: 400 rabbits.ha⁻¹, T8: 800 rabbits.ha⁻¹, T12: 1200 rabbits.ha⁻¹, T16: 1600 rabbits.ha⁻¹ of rabbits housed over fish ponds

Performance parameters	Treatment (number of rabbits housed over the fish pond)					LSD _{0.05}
	T2	T4	T8	T12	T16	
Fish stocking rate (fish/m ²)	2	2	2	2	2	
Mean weight at stocking (g)	13.2±1.1 ^a	14.7±0.8 ^b	12.0±0.3 ^a	32.79±9.5 ^c	12.3±0.5 ^a	1.6 **
Mean weight at harvest (g)	30.9±3.5 ^a	38.4±2.5 ^b	46.8±4.6 ^c	70.7±1.6 ^d	52.1±3.8 ^c	5.3 **
Daily weight gain (g.day ⁻¹)	0.2±0.04 ^a	0.3±0.03 ^b	0.41±0.0 ^c	0.3±0.01 ^b	0.47±0.0 ^c	0.1 **
Specific growth rate (%.day ⁻¹)	0.9±0.1 ^a	1.0±0.1 ^a	1.6±0.1 ^b	0.7±0.02 ^c	1.7±0.1 ^b	0.2 **
Survival rate (%)	85.2±11.3 ^a	91.4±1.84 ^a	84.2±9.6 ^a	89.2±4.4 ^a	72.5±9.1 ^b	13.7 ns
Net fish yield (kg.ha ⁻¹ .yr ⁻¹)	1133.9	18.4.37	2382.33	3255.9	2213.7	
	±230 ^a	±204.6 ^b	±184.5 ^b	±151.4 ^c	±204.4 ^b	619.9 **

Mean values± SE with same superscript letters in the same row are not significantly different ($P < 0.05$). LSD (5% level): Least Significant Difference obtained by Analysis of variance for repeated measurements was used to separate different means.

Whilst T12 exhibited the highest NFY peak of the five treatments, this production started declining in the treatment composed of 16 rabbits per area of pond. Table 5.3 shows the mean data for rabbit droppings (solid dung and urine) per treatment and allows for the comparing of trends in daily excretion of droppings and daily fish growth and production). The average amount of droppings discharged daily tends to increase with increasing rabbit densities but the change according to rearing time did not occur in a regular way, as shown in Figure 5.1. A strong relationship was revealed by a polynomial regression analysis, between the amount of rabbit dung and the NFY per treatment with $R^2 = 0.90$ and equation $y = 0.5 + 1.4x - 0.1x^2$. y representing the net yield NFY and x the rabbit dung.

Table 5.3: Change in rabbit droppings (mean quantity over rearing time) in relation with net fish yield in ponds fertilised by different rabbit densities over ponds: T2: 200 rabbits.ha⁻¹, T4: 400 rabbits.ha⁻¹, T8: 800 rabbits.ha⁻¹, T12: 1200 rabbits.ha⁻¹, and T16: 1600 rabbits.ha⁻¹.

Treatment	Droppings		Tilapia	
	Dung (kgDM. ha ⁻¹ .day ⁻¹)	Urine (L. ha ⁻¹ . day ⁻¹)	NFY (kg. ha ⁻¹ . day ⁻¹)	DWG (g. day ⁻¹)
T2	6.0	25.6	3.1 ^a	0.2 ^a
T4	16.1	17.9	5.0 ^b	0.8 ^b
T8	26.2	41.7	6.5 ^b	0.4 ^c
T12	22.0	15.9	8.9 ^c	0.3 ^b
T16	35.5	192.9	6.1 ^b	0.5 ^c

kgDM. ha⁻¹. day⁻¹: kg dry matter per hectare and per day, L.ha⁻¹.day⁻¹: Litre per hectare per day; g. day⁻¹: gram per day

5.4 Discussion

Water quality parameters

Although some physico-chemical parameters reached critical limits, especially in treatment T16 (1600 rabbits.ha⁻¹ of pond), in general the water quality parameters were within favourable limits for Nile tilapia growth (Teichert-Coddington and Green, 1997; Van Rijn, 1997; Knud-Hansen *et al.*, 1998). Nevertheless, almost all water quality parameters which affect fish productivity in ponds differed with an increase in rabbit density.

Characteristics of deteriorated fishponds were thus observed, for example, in T16 which recorded significantly higher ammonia content and lower Secchi transparency and dissolved oxygen. The lower Secchi transparency recorded in T16 may have been caused by phytoplankton blooms, as supported by the negative correlation between the Secchi transparency ($r = -0.5691$; $n = 15$) and the daily primary productivity (DPP). Earthen ponds are very often built in marshes that are rich in clay which is, in most fish culture systems, the main cause of turbidity. Paradoxically, chlorophyll *a* was significantly correlated ($r = 0.726$; $n = 15$) with a linear positive relationship ($R^2 = 0.526$; $P = 0.002$) to the varying rabbit dung amount.

The temperature did not differ significantly within treatments and ranged within acceptable limits (20.5–23.6 °C) of mean temperature. Mean values for pH (6.70–6.90) were included in the favourable range for aquatic organisms' growth (Knud-Hansen *et al.*, 1998; Garg and Bhatnagar, 2000; Boyd and Queiroz, 2001). High pH values in ponds play an important role in the transformation that occurs regarding inorganic nitrogen forms from un-ionised forms susceptible to being toxic, to ionized forms which are a non-toxic ammonia form.

After recording a low range of pH 7 to 8 in a study on nutrient and microbial dynamics, (Burford *et al.*, 2003) argued that the pH was responsible for the harmless inorganic nitrogen observed in shrimp ponds but (Engle *et al.*, 1993) reported that, in ponds with dense phytoplankton blooms, daily fluctuations of pH between 6.5 and 9.5 were not uncommon. In fertilised or fed ponds, pH values increase during the day in general and in the afternoon in particular (values always between 8.5 and 9.5), due to the removal of carbon dioxide by phytoplankton for use in

photosynthesis (Boyd *et al.*, 2000). pH values decrease during the night, as carbon dioxide accumulates due to the absence of photosynthesis.

Mean dissolved oxygen (DO) at dawn in the current study, showed significant differences between rabbit densities: treatments with the lowest densities (T2 and T4) being the only ones showing suitable mean DO for Nile tilapia. The overall change with time in mean DO showed depletion in almost all treatments 70 days after stocking, a period during which ponds deteriorated across many water quality parameters, especially ponds receiving droppings from higher rabbit densities. This is supported by the DO negative correlation to rabbit dung voided into ponds ($r = -0.796$, $n = 15$), the same DO concentration being positively correlated to ionized ammonia change ($r = 0.712$, $n = 15$); conditions that are likely to lead to a depletion in fish production. Although DO was negatively correlated to net fish yield (NFY $r = -0.690$), a weak relationship was observed between $\text{NH}_4\text{-N}$ and NFY ($r = 0.0057$, $n=15$). These fluctuations in DO and $\text{NH}_4\text{-N}$ are likely to have caused stressful conditions which resulted in the recording of low NFY and fish survival rates (SR) for Nile tilapia in T16.

Inorganic nitrogen ($\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$) fluctuated substantially, showing significant differences, except for $\text{NO}_3\text{-N}$, within treatments. Two treatments, T12 and T16, recorded respectively nitrites and ammonia values that drew attention for their impact on fish life. Nitrites and ammonia levels in water, especially in tropical conditions, are potentially subject to fluctuations during the day, as the equilibrium concentration within ionized and non-ionized ammonia is a function of temperature and pH. Highly concentrated non-ionized ammonia (NH_3) is toxic to fish (Van Rijn, 1997; Boyd and Tucker, 1998; Knud-Hansen *et al.*, 1998). In the current study, only the treatment with the highest rabbit density (T16) showed a high concentration of ammonia with a level harmful ($\text{NH}_4\text{-N} > 1.0 \text{ mg.l}^{-1}$) to Nile tilapia. Its negative impact in this treatment can be seen in the survival rate and net fish yields.

The later observation on ammonia corroborates Kaliba *et al.* (2006) findings which showed that high ammonia levels were responsible for low survival rates for most fish. The values of pH indicated that none of the treatments reached the toxic form of ammonia (that is the non-ionized ammonia) which usually occurs at $\text{pH} > 9$ (Boyd *et al.*, 2000). Therefore the higher values of

ionized ammonia (that is $\text{NH}_4^+ > 1 \text{ mg.l}^{-1}$) could be accountable for the recorded loss in fish, as the overall pH ranged between 5.4 and 7.44 as extreme values for this study.

Nitrites were more elevated in T12 than in any other treatment as a consequence of low DO and pH. Nitrifying bacteria might not have been stimulated enough to set off the transformation of nitrites into nitrates. The observed nitrite value ($1.0 \text{ mgNO}_2\text{-N.l}^{-1}$) was still at the extreme limit acceptable for tilapia (Timmons *et al.*, 2002, in Sesuk *et al.*, 2009) and no high mortality or even stress was observed in T12 ponds. The main origin of inorganic nitrogen in ponds was assumed to be the bacterial decomposition of rabbit dung. The multiple linear regression on some measured parameters (DO, $\text{NH}_4\text{-N}$, Chl-a, DPP, NFY, SR) with rabbit droppings as response variate, confirmed inorganic nitrogen (ammonia) as significantly related to excreted rabbit dung ($R^2 = 87.5\%$; $P = 0.006$). This suggests that continuous increasing of rabbit densities is likely to lead to a deterioration of the fishpond environment. This also corroborates findings in previous studies that reported an increase of nitrates, ammonia and phosphates with increasing fertiliser doses (Garg and Bhatnagar, 2000; Diana *et al.*, 2004).

Plankton composition and abundance

While some authors argue that manure can be consumed by fish (Franco, 1991; Breine *et al.*, 1996), Schroeder (1980) in Hopkins and Cruz (1982 supported the role of supplying nutrients for phytoplankton to provide a substrate for heterotrophs, the main natural food-source for fish besides phytoplankton. Rabbit manure is known to be richer than other farm animals' manure including that of cattle, pigs, chickens, and ducks (Lebas *et al.*, 1996; Kumar and Ayyapan, 1998; Lukefahr, 2007). In the current integrated agriculture aquaculture (IAA) system, rabbit droppings were assumed to regularly increase with increasing rabbit density and biomass, with a consequent probability of plankton bloom. Plankton and its abundance were assessed in order to highlight the composition of the main plankton community in this specific type of IAA system that integrates rabbit production with aquaculture. The *Euglenophyceae* family, algae that characterise eutrophic water bodies, appeared as the most abundant phytoplankton group followed by the *Chlorophyceae* family.

For a better assessment of the impact of rabbit densities on phytoplankton development, analysis of the concentration of chlorophyll *a* (Chl *a*) and quantification of the daily primary productivity (DPP) for each treatment were carried out. Chl *a* concentration increased with increasing rabbit densities, without depletion, T16 having the significantly highest Chl *a*. DPP was significant highly concentrated in T12 while very low in all other treatments.

These phytoplankton productivities ($0.15\text{--}1.86 \text{ g C.m}^{-2}\text{.day}^{-1}$) were slightly lower than those ($0.94\text{--}1.23 \text{ g C.m}^{-2}\text{.day}^{-1}$) reported by [Azim *et al.* \(2001\)](#) in ponds with artificial substrates and various frequencies of fertilisation. Positive significant correlation was thus established between Chl*a* and rabbit dung excreted by each rabbit density in this study ($r = 0.7247$; $P = 0.006$). This relationship implies the importance of the role played by phytoplankton biomass (Chl *a*) in boosting tilapia growth and production ([Garg and Bhatnagar, 2000](#)). The authors of this study found a similar relationship when studying the effect of fertilisation frequency on pond productivity and reported a positive correlation between fish yield, phytoplankton and primary production. [Garg and Bhatnagar \(2000\)](#) also pointed out that [Ryther and Yentsch \(1958\)](#), [Zur \(1981\)](#) and [Almazan and Boyd \(1978\)](#) had observed similar correlations.

Furthermore, the NFY also had a significant relationship with rabbit dung deposited continuously into ponds ($R^2 = 0.544$; $P=0.004$) which suggests that nutrients from rabbit droppings might be the basis for Nile tilapia growth and production in the present system. The T16 treatment appears to have become rapidly eutrophic, with phytoplankton blooms that were likely to raise turbidity and plankton die-off, hence contributing to a rise in ammonia. Phytoplankton blooms might have blocked light for photosynthesis activity that lowered DPP and consequently negatively affected fish production. It seems therefore, that increasing rabbit densities would continue to lead to a deterioration of pond quality and would decrease net fish yield as shown in Table 5.4, which shows that peak fish production was in treatment T12.

Comparison between the current results and reports from previous researches on optimisation of fertilisation from other animals (Table 5.4), demonstrates that integrated rabbit–fish culture is able to generate fish production ($\pm 9 \text{ kg.ha}^{-1}\text{.day}^{-1}$ which is $3.3 \text{ t.ha}^{-1}\text{.yr}^{-1}$) with low amounts of dung ($22 \text{ kgDM.ha}^{-1}\text{.day}^{-1}$) when compared to systems using the dung of pigs, chickens and

ducks, which yield 4–6 t.ha⁻¹.yr⁻¹ of fish with 5 times the amount of dung as that used in the rabbit–fish system.

Even though the comparison is made, it should be remembered that animals in Table 5.4 were fed appropriate pelleted feed, except for rabbits, and this would have led to enriched manure. Nevertheless, manure from rabbits fed grass only was reported to be richer in nitrogen (2.88%) and phosphorus (1.68%) by two to four times compared to that of chickens and pigs respectively (Van Vleet, 1997). The rabbit–fish system seems to be relatively more affordable for rural farmers farming fish on a small–scale but a regular monitoring of water quality parameters is advised in order to intervene early by renewing water when needed, or by using the optimal manure application rate and/or number of animal sources of fertilisers.

Fish growth and productivity

Fish growth and fish survival are two main determinants of fish yield (Hopkins and Cruz, 1982; Teichert-Coddington and Green, 1993; Knud-Hansen *et al.*, 1998). As the current study was an on-station research intending to assess the effect of rabbit droppings based on the number of animals raised on ponds, the rearing time for each experiment was relatively short (maximum of 98 days) and the amount of applied fertilisers could not be fixed at the start of the experiments. Fish growth and production performances are discussed based mainly on parameters such as mean weight at harvest, specific growth rate (SGR), net fish yield (NFY), and survival rate (SR) calculated at harvest after draining of ponds. Better fish production (NFY) was obtained in general, in ponds with high rabbit densities (T8, T12, and T16) but T12 recorded a NFY significantly higher ($p < 0.05$) than other treatments.

This suggests that fish production is dependent on manure load but this is not indefinite, many other parameters intervene in influencing fish production (for example density of rabbits, water quality, fish density) Fish production in T16 was significantly lower than in T12 and even slightly lower compared to T8, due probably to a relatively long exposure to harmful levels of ammonia associated with lower dissolved oxygen which might have caused the high mortality (~28%) recorded in these ponds. Other sources of fish loss may have contributed to the mortality reported in this study. It is normal in aquaculture experiments that mortalities occur due to

manipulation at every fishing for growth control, also predation by birds as we did not observe any fish kills, can significantly contribute to loss of fish.

[Hopkins and Cruz \(1982\)](#) reported an increase in fish production with an increasing number of chickens, up to 5 000 chickens.ha⁻¹ over fishponds for optimal production, corresponding to 100–110 kg dry matter.ha⁻¹.day⁻¹ of chicken manure but thereafter they observed a decrease in fish production with densities higher than 5 000 chickens per ha of pond (Table 5.4). The same authors also observed similar trends for pig and duck manure. Likewise, previous studies on the effect of fertilisation frequency ([Garg and Bhatnagar, 2000](#)) and on the optimisation of fertilisation rates ([Azim et al., 2001](#)) mention that fish biomass and SGR are correlated with a high release of nutrients.

Table 5.4: Optimal animal manure loads studied for integrated aquaculture–livestock compared to the optimum from the present study for rabbits (Tilapia stocking rate = 2 fish.m⁻²)

Source of fertilisation	Optimum manure (kgDM.ha ⁻¹ .d ⁻¹)	Number of animals per hectare	Net Yield (kg.ha ⁻¹ .d ⁻¹)	Fish NFY (g)	Meanw eight (g)	growth rate (g.d ⁻¹)	Study
Cows	^a 90 - 100	-	13.7	-	1.547	(Azim et al., 2001)	
Pigs	101 -110	100-140	19.2	112	1.2	(Hopkins and Cruz, 1982; Kumar and Ayyapan, 1998)	
Chickens	97-110	5000	16.4	137	1.5	(Hopkins and Cruz, 1982)	
Ducks	82 - 136	2250	11.9	87	0.8	(Hopkins and Cruz, 1982; Kumar and Ayyapan, 1998)	
^bRabbits	^b22 and 15	1200	8.9	70.7	0.32	This study	

a: (4500 kg.ha⁻¹ fortnightly); b= 22 kgDM.ha⁻¹.day⁻¹ of dung and 15 L.ha⁻¹.day⁻¹ of Urine obtained without formulated pellet for rabbits.

Moreover, the assessment of amounts of droppings voided daily into fishponds in the present study showed an increase of droppings with increasing density of rabbits but not in a regular manner. The fluctuation observed in quantity of voided wastes by rabbits is very common in rabbit husbandry because various events lead to digestive disorders in a rabbit’s gut followed by diarrhoea, very often discreet and mostly preceded by a subtle halt in production of wastes. Events susceptible to cause diarrhoea in rabbits include variations in micro-climate, nature and quality of food, persistent noise, transport within the farm and a decline in hygiene conditions

(Finzi and Amici, 1991; Lebas *et al.*, 1996). The authors highlighted that rabbits suffering from diarrhoea produce significantly less dung than healthy rabbits and all causes of diarrhoea lead to a decline in rabbit daily weight gain.

5.5 Conclusion

Referring to the wide potential offered by the IAA system and the richness of rabbit droppings, an animal found widely in Rwandan households, the study focused on rabbits' role in an IAA system, optimising the rabbit density that would be suitable for sustainable water quality and fish production, led to the following conclusions:

Based on water quality, plankton and fish production in the studied system, the optimisation of fertilisation must be based on the changes that occur due to inorganic nitrogen transformations that lead to pond water deterioration and a decrease in fish production. Even though it is difficult to base the decision on several parameters, the optimal rabbit density was 800 and 1200 rabbits ha^{-1} fish pond, corresponding to approximately 22 to 26 $\text{kg DM ha}^{-1} \text{d}^{-1}$ of rabbit dung and 15 to 41 $\text{litres ha}^{-1} \text{d}^{-1}$ of urine. It is in this range of rabbit densities that the highest fish yields, the best growth rates (DWG and SFR) and the best environment for tilapia growth were observed. However, at a higher density than these, the fish yield began to decrease.

Further studies should focus more on one experimental design for the same or more rabbit densities, in order to overcome the variability resulting from various experiments over various lengths of times. Studies should be conducted on the optimisation of fertilisation by rabbit droppings, where rabbits are fed on formulated pellets to assess fish yield and water quality, considering that rabbit dung is rich in nitrogen and likely to be directly consumed by fish. The flow of nutrients in this rabbit–fish system, and its economic efficiency, both need to be studied further.

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6. CHAPTER SIX: Nutrient Flow in an Integrated Rabbit–Fish– Rice System in Rwanda

The following article is based on chapter 6:

Rukera Tabaro, S., Mutanga, O., and Micha, J-C. n.d. Nutrient Flow in an Integrated Rabbit–Fish–Rice System in Rwanda. Submitted in *the International Journal of Biological and Chemical Sciences*.

Abstract

An analysis of nutrient flow, based on nitrogen (N) and phosphorus (P), was conducted on an integrated rabbit–fish–rice system (IRFR) system at the Rwasave Fish Farming Station (National University of Rwanda). Rabbits, stocked at 12 per are (1200 rabbits.ha⁻¹) of pond, were reared over fishponds stocked with one and three male Nile tilapia (*Oreochromis niloticus* L.) per m² for pond treatments PT1 and PT2. Effluent fertilised by the rabbits was drawn away from the ponds by pipes installed at the bottom of the ponds to irrigate rice (*Oryza sativa* L., variety *Yuni yin4*) fields. There were six 400 m² ponds and nine 90 m² rice fields; three of the latter were irrigated by canal water and fertilised by NPK (200 kg.ha⁻¹.crop⁻¹, 2 applications; 100 kg.ha⁻¹.crop⁻¹, one application).

The results showed that rabbit droppings supplied about 27% N and 79% P of the total N and P inputs, fertilising the ponds at a rate of 3.98 kg N and 1.94 kg P.ha⁻¹.day⁻¹. The Nile tilapia fish recovered 18.5-7.6% N and 16.9–34.3% P of the total nitrogen (TN) and total phosphorus (TP) inputs. All water quality variables remained within good limits for tilapia aquaculture and nutrient distribution was not dependent on fish density. Large amounts of N and P accumulated in the water, sediment, and effluent fertilised rice fields at a higher rate (118.5 kg N and 27.2 kg P.ha⁻¹.day⁻¹) than that of inorganic fertilisers, resulting in a slightly higher rice yield than that induced by NPK and urea.

Tilapia effluent was thus able to substitute inorganic fertilisers completely, allowing savings to the farmers, and showing its potential as a fertiliser for fish and crop production rather than waste to be discharged, polluting the environment by its solids and organic matter component. Further studies involving a thorough analysis of nutrients lost and diversified uses of the nutrient-rich effluent are needed.

Keywords:

Flux of nutrients, integrated agriculture-aquaculture system, nutrient-rich effluent, rabbit–fish–rice system, earthen ponds.

6.1 Introduction

During recent years, aquaculture has developed worldwide for the purpose of addressing food insecurity and income generation. In aquaculture, ponds are dynamic ecological systems that continuously process and remove large quantities of nutrients and organic material (Cathcart *et al.*, 1999). This has led to large quantities of pond nutrients (total solids and organic matter) being discharged, generally into natural water bodies, where they constitute a major source of water pollution, especially in semi-intensive and intensive aquaculture systems in countries where farmers lack effluent management techniques.

Earlier aquaculture enterprises are either extensive or semi-intensive fish farms, integrated to agriculture (crop and/or livestock) or not (that is stand-alone enterprises). The latter are intensive systems or recirculated aquaculture systems (RAS) which, when operating on a larger scale, are risky ventures and are not suitable for resource-poor farmers in developing countries (Prein, 2002). They require formulated fish feeds and operate using high level energy and high investments. Consequently, these systems cause high risks including water quality deterioration through accumulation of nutrients in water and pond bottom soil, diseases, low profit margins; furthermore, they lead to impacts such as pollution, environmental destruction, and reliance on pelleted feeds (Naylor *et al.*, 2000). Extensive and semi-intensive aquaculture relies on fertilisation and used crop by-products for supplements to fish feeds. These are often integrated agriculture-aquaculture (IAA), less risky systems because they benefit from synergisms from constituent enterprises, have a diversity in produce as well as environmental soundness (Edwards, 1998; Prein, nd).

The nutrient budget of fishponds in conventional aquaculture explains that only small portions of inputs are recovered in fish biomass and in water columns, with the largest amounts lost in pond bottom mud (Knud-Hansen *et al.*, 1998; Yi *et al.*, 2002; Lin and Yi, 2003). During fish harvest by the draining of the ponds, nutrients in the upper layer of mud are carried away in the effluent and released into rivers. The most important nutrients in fertilised fishponds are N and P which, in key concentrations, are limiting for phytoplankton growth. N and P, in intensive aquaculture systems are also reported the two main pollutants of water (Håkanson *et al.*, 1998; Lemarié *et al.*, 1998).

The feeding and fertilisation of fishponds, with fish feed and fertilisers always result in the accumulation of nutrients in the form of fish waste and other organic matter. In this regard, observations made of channel catfish (*Ictalurus punctatus*) and hybrid catfish (*C. macrocephalus* x *C. gariepinus*) ponds, reported an increase of most water quality variables, including nutrients, total solids, organic matter, and a high 5-day biochemical oxygen demand in the remaining 25% of effluent when fishponds are being drained (Boyd, 2001b; Boyd and Queiroz, 2001; Tucker and Hargreaves, 2003). This last part of pond effluent is potentially harmful to the environment as it often contains more than 50% of the total load of nutrients (Boyd, 2001a), 35.5% TN and 10.4% TP (Yi *et al.*, 2006).

Aquaculture wastewater, because of its load of nutrients, could be seen as a potential fertiliser for fish farming and agriculture production (Wood *et al.*, 2000) more generally in integrated agriculture-aquaculture (IAA) systems (Prein, 2002; Nhan *et al.*, 2006) rather than a waste to be discharged and to pollute water bodies (that is the environment water entity, rivers, lakes, swamps) by solids and organic matter. IAA farming is characterised by the recycling of nutrients between the farm components (Edwards, 1998; Devendra and Thomas, 2002; Prein, 2002) and this system allows the intensification of production and income generation while reducing environmental impact (Nhan *et al.*, 2006). Tropical integrated pond systems are reputed to retain nutrients to a high degree as the latter are re-used by primary and secondary producers, making the system a better nutrient converter than the recirculation aquaculture systems (Liu and Cai, 1998).

In the current study, nutrient-rich wastes were dropped directly into fishponds from grass-fed rabbits and pond wastewater (that is, fertilised effluent) was then used as fertiliser for irrigated rice. The flow of bio-resources and nutrients throughout the rabbit–tilapia–rice integrated system was investigated, with the rabbits as the major entry point for nutrients in the system (Thorne and Tanner, 2002). The objective of this study was to identify the flow of nutrient by quantifying the mass flow of N and P nutrients by using the mass balance approach, assuming that IAA farming allows the recycling of nutrients between farm components.

6.2 Materials and Methods

6.2.1 Site and experimental arrangement

The present study was carried out at the Rwasave Fish Culture Research Station (SPIR) of the National University of Rwanda (geographic co-ordinates 02° 36' 10'' S and 29° 45' 25'' E and elevation about 1,625 m above sea level). The SPIR–NUR is located at Butare in Huye district in the Southern Province of the Republic of Rwanda (Figure 3.3). A detailed diagram of the agriculture system implemented at the SPIR combined with an annotated photograph is given on Figure 3.2. The experiment used three different living organisms, namely rabbits (*Oryctolagus cuniculus* L.), fish (*Oreochromis niloticus* L.), and rice (*Oryza sativa* L., var *yuni yin4*); these were all farmed as parts of a full IAA system.

6.2.1.1 Rabbit housing

Rabbit hutches were built and placed over the fishponds to allow all rabbit droppings to fall straight into their respective fishponds. Each hutch was divided into four cages, each 0.7–1 m in height with a 1 m² wire mesh floor. Three hutches were installed over each fishpond of 4 ares (400 m²). The rabbits were placed in their hutches one week before the ponds were stocked with fish and two weeks before the rice was transplanted into the adjoining fields. The rabbits were a local strain of the *Oryctolagus* genus, and were stocked at a density of 1200 rabbits per hectare of pond (that is 4 rabbits per m² hutch floor making 48 rabbits per 400 m² fishpond area). Four rabbits were stocked per cage, making 48 rabbits per pond, or 12 rabbits per acre. The mean live weight of each rabbit was 600–800 g. The rabbits were fed with cut grass, brought in from the pond dykes and the station surrounds. Rabbit health was attended to: the only disease that was frequently observed was rabbit gall, and this was treated by subcutaneous injections of Ivermectin and sometimes by skin application of motor or crankcase oil.

6.2.1.2 Fishponds and rice fields

Before the experiment began, the fishponds were drained, dredged, and dried to minimise any possible effect of prior use. The inlet pipes were blocked by a fine mesh net to avoid wild aquatic species, such as frogs, molluscs, and wild fish, being carried into the pond by the flow of water in the canals that connected the ponds to the Rwabuye River.

Each fishpond was connected to a 90 m² (9 m x 10 m) rice field by a PVC outlet pipe, installed about 10 cm from the bottom of the pond for the irrigation of the rice fields (Figure 3.2). Two small PVC pipes, perforated along their length (8 m), were installed at a depth of 40 cm in each of the rice fields to drain the pond water after it had seeped through the rice field soil.

The experiment commenced on 24 August 2009, on the day the rice was transplanted. This was two weeks after the rabbit hutches were stocked and the ponds filled with water. The experiment ended on 25 January 2010, the day the rice was harvested.

6.2.1.3 Experimental management

The aim of the experiment was to use rabbit droppings to fertilise fishponds, thereby producing well-grown fish as well as fertilised pond water (effluent) that could then be used to irrigate rice fields; this would simultaneously reduce the discharge of nutrients from the fish culture ponds into the environment.

The experiment consisted of two treatments in a completely randomised design with three replicates (Gomez and Gomez, 1984). Hand-sexed, monosexual juvenile male Nile tilapia were used for their grow-out phase. The six fishponds were each connected to their own rice field of 90 m². The experiment was then conducted in six fishponds of four acres (400 m²) each and in nine rice fields of 90 m² (9 m x 10 m) each. The following treatments took place in the fishponds:

- Pond treatment 1 (PT1): three of the six fishponds were stocked with one fish per m² and were fertilised with the droppings from 1200 rabbits per hectare of pond.
- Pond treatment 2 (PT2): three of the six fishponds were stocked with three fish per m² and were also fertilised by dropping from 1200 rabbits per hectare of pond.

With regard to the rice, the following three treatments took place:

- Rice treatment 1 (RT1): three of the nine rice fields were fertilised by chemical fertilisers (NPK: 17:17:17 and urea 45%-N).
- Rice treatment 2 (RT2): three of the nine rice fields were fertilised by the effluent of the fishponds stocked with 1 fish per m² (see PT1).
- Rice treatment 3 (RT3): three of the nine rice fields were fertilised by the effluent from the fishponds stocked with three fish per m² (see PT2).

6.2.2 Dynamic of nutrients in the rabbit–fish–rice integrated system

6.2.2.1 Composition of rabbit droppings and rabbit feed

Every two weeks, a 24-hour cycle collection of droppings (both rabbit dung and urine) was conducted. The dung, taken from under one cage lodging four rabbits, was collected twice a day, at 07h00 and 16h00 for night and day excreted amounts respectively. All overnight excretion, both dung and urine, was collected at 07h00. Urine excreted during the day was collected, and the volume recorded, every two hours during the day to minimise loss through evaporation; subsequently, it was poured back into the fishpond.

The biochemical composition of the droppings was determined by the laboratory of the Animal Science and Poultry Department, University of KwaZulu-Natal. The analysis determined the concentration of N, P, Ca, gross energy, fibre, fat, ash, and moisture using the ALASA method for feed and plants detailed in [AOAC \(1990\)](#). The same analysis was carried out for the composition of the rabbit forage, the rabbit pellets, fish carcasses, and rice at harvest. N was determined on a LECO TruSpec Nitrogen Analyser according to Official Method 990-03 and expressed as percentage protein ([AOAC, 1990](#)).

6.2.2.2 Water quality in fishponds

Water quality parameters, including dissolved oxygen, water temperature, pH, and electrical conductivity, were monitored on a daily basis, twice per day, using appropriate manual probes.

Chlorophyll *a* was determined after filtrating water on Whatman paper microfibre GF/C (retention: 1.2 μm ; $\text{Ø}47$ mm) and was analysed using the acetone extraction method (Descy, 1989).

Pond water nutrients, including N and P forms, were analysed from a sample collected fortnightly. A one litre sub-sample was filtered through Whatman filter paper and kept in the fridge for later laboratory analysis. Another litre of non-filtered water was analysed for TN and TP. TN was analysed using the Kjeldhal method (Blume, 1966) and adapted by [Léonard and Kanangire \(1998\)](#); TP was determined after hydrolysis into ortho-phosphates by persulfate digestion ([Wetzel R.G. and Likens G.E., 1979](#)), thereafter with the colorimetric method. Ortho-phosphate analysis was carried out on filtered water following the ascorbic acid method ([Descy, 1989](#)). Inorganic N, $\text{NH}_4\text{-N}$ (mg/l) and $\text{NO}_2\text{-N}$ (mg/l), was determined by the colorimetric method, while $\text{NO}_3\text{-N}$ was analysed using the cadmium reduction method ([APHA, 1985](#)).

6.2.2.3 Water seeping through rice field soil

A one-litre sample of seepage water was collected at the drains (perforated PVC tubes) that had been installed at a depth of 50 cm under the rice field. The sample was a mixture of water collected from the two drains installed in each. One half of the sample (that is, 500 ml) was filtered for $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, and $\text{PO}_4\text{-P}$ analysis; the second half was not filtered for TN and TP dosage. Nutrient analysis was done using the same procedures as described above for the pond water nutrients.

6.2.2.4 Nutrient analysis in soil samples

The analysis parameters used for the soil samples that were collected at the start, the midterm (90 days after transplanting DAT), and the end (153 days DAT) of the experiment were TN, nitrates ($\text{NO}_3\text{-N}$), ammonia ($\text{NH}_4\text{-N}$), TP, and phosphates ($\text{PO}_4\text{-P}$). The soil samples were collected using a soil auger along a “double S” trajectory in the fishpond and a “W” trajectory in the rice field. Samples were taken from a mixture of eight clumps of soil both for fishponds and rice fields.

Soil pH was measured by the electrometric method in a soil-solvent suspension, and cation exchange capacity (CEC) was analysed on a saturated soil as detailed in IITA (1975, adapted by Léonard and Kanangire (1998)). The TN was analysed using the Kjeldahl method according to INEAC (1959), adapted by Léonard and Kanangire (1998), and $\text{NO}_4\text{-N}$ ammonium and $\text{NO}_3\text{-N}$ nitrates from soil were determined according to the method detailed by McKeague (1978), adapted by Léonard and Kanangire (1998). The TP in the pond sediment and rice field soil was analysed using the spectrometric methods detailed in Pauwels *et al.* (1992a), and the $\text{PO}_4\text{-P}$ was determined by extraction followed by the blue-colorimetric method set out by Termminghoff (2000a).

6.2.3 Statistical analysis

Water and soil quality are subject to change over time when receiving rabbit droppings constantly. Measurements for water and soil quality were taken on replicates and the mean values were compared using a two-way analysis of variance (ANOVA II) for parameters changing over time. Significant differences among the treatments as shown by ANOVA were further tested using the least significant differences of means at a 5% level ($\text{LSD}_{0.05}$). Possible relationships between the parameters were analysed through regressions and correlations analysis using GenStat statistical software (GenStat12.1 Ed[®], 2009 – VSN International Ltd), which was also used for ANOVA.

6.3 Results

6.3.1 Rabbit nutrition, excretion of droppings and discharge of nutrients

Rabbits were fed forage *ad libitum* but formulated pellets were supplied only during the first month to supplement the ration in order to help the rabbits adapt to the new environment. The bromatological composition of forage, as well as that for rabbit droppings (both for rabbit fed forages or formulated pellets, is detailed in Table 6.1.

The average amount of dung ranged from 0.44 to 0.85 kg.are⁻¹.day⁻¹, and the average amount of urine ranged from 0.86 to 1.69 l.are⁻¹.day⁻¹. These wastes fluctuated widely over the rearing time, and no significant difference was found between the amounts of droppings (P<0.001) of the various treatments being voided into the fishponds. Rabbit dung was rich in basic nutrients for plankton development (Table 6.1.). Rabbit wastes were composed of 1.57 or 1.71% N and 0.62 or 0.34% P content when rabbits were fed on grass or formulated pellets, respectively. The rabbit urine might be an important source of nutrients in view of its composition 2.17% N and 1.15% P.

Rabbit waste was the major source of organic nutrient in the current IAA, providing about 505.10 kg TN and 245.87 kg TP to fishponds during the 127 days of pond fertilisation monitoring. The largest amounts of TN (1365 kg) and of TP (65 kg) were sourced from the canal water used to refill the pond during the culture period. Waste weight increased significantly in time (P = 0.02) with increasing rabbit weight. The present study identified a good rabbit growth with a daily weight gain of 8.0 g.day⁻¹ while the mean weight changed from 821.03 to 1362.7 g with a survival rate of 85.4%.

6.3.2 Fish, and rice yields

In treatments PT1 and PT2 (1 and 3 fish.m⁻² stocking density), total fish yield was 953 and 1939 kg.ha⁻¹, respectively. Fish mean weight of 104.3±4.2 and 70.7±1.6 g.fish⁻¹ was obtained in TP1 and TP2 respectively (productions are given and discussed in Chapter 7). Recorded rice yields were 5.79, 5.44, and 5.87 t.ha⁻¹ in RT1, RT2, and RT3, respectively and rice straw biomass was 10.79, 9.97, and 9.70 t.ha⁻¹. The fish and rice content in N and P nutrients is shown in Table 6.1.

Table 6.1: Chemical composition of the rabbit forage, droppings from rabbits fed on forage and rabbits fed pellets, highlighting the contribution of the rabbits to the integrated rabbit–fish–rice system. (N: nitrogen, P: phosphorus, K: potassium, Prot: crude proteins, G.E: gross energy, Ca: Calcium)

Items	Amount	Chemical composition									
		N (%)	P (%)	K (%)	Prot. (%)	Fibre(%)	Ash (%)	Moist. (%)	Fat (%)	Ca (%)	G.E (MJ.kg ⁻¹)
Rabbit forage (kg/12rabbits/day)	5	2.4	0.22	1.94	14.97	21.73	12.67	8.17	2.85	1.24	17.01
Rabbit pellets (kg/12rabbits/day)	6	2.91	0.86	--	18.19	13.11	9.81	10.05	9.15	0.88	15.45
Rabbit dung (fed forage) (kg/are of pond/day)	0.60± 0.1	1.57	0.62	0.38	9.82	33.84	13.63	8.1	4.56	1.43	17.78
Rabbit dung (fed pellet)	--	1.71	0.34	--	10.71	35.04	10.85	8.2	3.11	0.76	17.48
*Rabbit urine (l/are of pond/day)	1.36± 0.3	2.17	1.16	--	--	--	--	--	--	--	--
Rice straw		1.48	0.31	--	9.23	28.22	15.21	--	1.43	0.36	15.45
Harvested rice grain		1.56	0.16	0.09	--	--	--	--	--	--	--
Harvested Fish		9.79	4.35	1.04	--	--	--	--	--	--	--

*Chemical composition from [Niyotwambaza et al. \(2010\)](#); --: data not available

6.3.3 Pond water quality

Table 6.2 presents the mean and standard error for listed water quality parameters and the major nutrients which characterised the pond water. The overall recorded water quality parameters range values were 20.4–29.9°C for temperature, 6.5–8.4 of pH, and 40–120 mg CaCO₃.l⁻¹ of total alkalinity in the ponds undergoing the range of treatments. All the parameters of the water quality remained within acceptable limits for pond aquaculture throughout the duration of the experiment. The temperature, DO, pH, and total alkalinity values were similar between treatments, but the DO, the pH, and the temperature recorded had significantly higher values in the afternoon than observed at dawn within the same treatment (Table 6.2).

Table 6.2: Physico-chemical parameters characteristics of fish pond water in rabbit–fish–rice integration system [ponds stocked with one (PT1) and three (PT2) fish per m² of pond]

Pond water parameters	Treatments			
	PT1	PT2	LSD _{0.05}	P value
Temperature (°C) a.m.	21.6 ± 0.22 ^x	21.8 ± 0.25 ^x	0.18 (*)	0.021
Temperature (°C) p.m.	25.1 ± 0.47 ^{ay}	26.0 ± 0.39 ^{bz}		
pH a.m.	6.9 ± 0.09 ^x	6.9 ± 0.05 ^x	0.25	0.017
pH p.m.	7.1 ± 0.44 ^y	7.1 ± 0.52 ^y		
Conductivity (µS.cm ⁻¹) a.m.	115.4 ± 5.32	118.5 ± 4.29		NS
Conductivity (µS.cm ⁻¹) p.m.	115.7 ± 5.64	117.7 ± 4.37		
Dissolved oxygen (mg.l ⁻¹) a.m.	1.9 ± 0.34 ^x	1.7 ± 0.85 ^x	2.23	<.001
Dissolved oxygen (mg.l ⁻¹) p.m.	9.6 ± 0.41 ^y	10.1 ± 0.88 ^y		
Secchi transparency (cm)	28.9 ± 1.37 ^a	26.6 ± 1.63 ^b	1.8 (*)	0.017
Total alkalinity (mg CaCO ₃ .l ⁻¹)	87.9 ± 8.73 ^a	85.0 ± 5.71 ^a	8.98	NS
Chlorophyll-a (µg.l ⁻¹)	41.1 ± 5.69 ^a	71.5 ± 14.69 ^b	30.11 (*)	0.002
Primary productivity (g C.m ⁻² .day ⁻¹)	1.7 ± 0.27 ^a	1.8 ± 0.26 ^a		
TN (mg.l ⁻¹)	3.2 ± 0.28	3.0 ± 0.17	1.03 NS	<.001
NH ₄ -N (mg.l ⁻¹)	0.1 ± 0.04	0.2 ± 0.06		NS
NO ₂ -N (mg.l ⁻¹)	0.1 ± 0.00	0.1 ± 0.00		NS
NO ₃ -N (mg.l ⁻¹)	3.3 ± 0.01	2.7 ± 0.00		NS
TP (mg.l ⁻¹)	0.6 ± 0.02	0.7 ± 0.01	0.49 NS	<.001
PO ₄ -P (mg.l ⁻¹)	0.5 ± 0.07 ^a	0.5 ± 0.09 ^b	0.113 (*)	0.012

The values presented above are means ± SE of mean. Data with different superscript letters (that is, **a** and **b**) in the same row and letters (that is, **x**, **y**, and **z**) in the same column for the same parameter were significantly different (P < 0.05). **NS** refers to no significant difference., daytime (07h00 to 08h00 for **a.m.** - before noon; 14h00 to 15h00 for **p.m.** - after noon) **LSD**_{0.05} is the least significant difference to which means are compared to point out the significance at 5% level.

Secchi disk transparency was higher (P<0.05) in the ponds stocked with one fish per m² than in those stocked with three fish per m².

The daily primary productivity ranged from 0.7 to 2.9 g C.m⁻².day⁻¹ for PT1 and from 1.1 to 2.8 g C.m⁻².day⁻¹ for PT2, with no significant difference (P<0.05) between treatments, whereas the

chlorophyll *a* concentrations were significantly higher in PT2 than those in PT1 ($P = 0.002$, Table 6.2). Regarding the nutrient concentrations in the pond water, there appeared to be no accumulation of inorganic N (ammonia, nitrites, and nitrates) as toxic levels were not reached in any of the treatments (Table 6.2). There was no significant difference between the treatments for all nutrients, except for the available P, for which the phosphate concentrations in PT2 were significantly higher than those in PT1 ($P < 0.05$).

6.3.4 Nutrients in water seeping through rice field soil

Samples of water that had filtered through rice field soil were analysed for N and P forms to assess the possible discharge of nutrients from the system to the underground environment. N forms did not differ significantly among the rice fields fertilised by effluent from ponds with one fish per m^2 (RT2) and those fertilised with effluent from ponds stocked with three fish per m^2 (RT3) (Table 6.3).

Water seeping in the fields treated by inorganic fertilisers (RT1) had higher concentrations ($P = 0.001$) of nitrates ($0.3 \pm 0.13 \text{ mg.l}^{-1}$) than water from fields of RT2 ($0.2 \pm 0.09 \text{ mg.l}^{-1}$) and RT3 ($0.2 \pm 0.08 \text{ mg.l}^{-1}$) treatment. The N concentrations, after seepage in RT1 fields, were slightly lower than those recorded in the pond effluent and water that flowed to irrigate the rice field. The TP concentration in water from the rice fields undergoing RT1 was significantly higher ($P < 0.05$) than those in water from the rice fields undergoing RT2 and RT3 (which were not significantly different from each other).

Table 6.3: Concentration of nutrients in the outflow after water has leached into the rice field soil. RT1: rice fields fertilised by NPK and urea; RT2: rice fields fertilised by effluent of fishponds stocked with one fish per m²; RT3: rice fields fertilised with effluent of fishpond stocked with three fish per m²

Treatment	Nutrients leaching through rice field soil					
	TN (mg/l)	TP (mg/l)	NH ₄ -N (mg/l)	NO ₂ -N (mg/l)	NO ₃ -N (mg/l)	PO ₄ -P (mg/l)
RT1	2.6 ± 0.77 ^a (1.05–5.67)	0.6 ± 0.24 ^a (0.1–1.3)	0.3 ± 0.08 ^a (0.015–0.545)	0.0 ± 0.01 ^a (0.001–0.066)	0.3 ± 0.13 ^a (0.052–0.825)	0.1 ± 0.04 ^a (0.036–0.273)
RT2	3.2 ± 0.89 ^a (1.330–6.370)	0.5 ± 0.16 ^b (0.1–1.1)	0.2 ± 0.06 ^a (0.010–0.456)	0.0 ± 0.01 ^a (0.004–0.040)	0.2 ± 0.05 ^b (0.019–0.354)	0.1 ± 0.07 ^b (0.025–0.419)
RT3	2.7 ± 0.65 ^a (1.33–5.67)	0.5 ± 0.11 ^b (0.2–1.2)	0.3 ± 0.09 ^a (0.044–0.552)	0.0 ± 0.02 ^a (0.003–0.066)	0.2 ± 0.05 ^b (0.044–0.825)	0.1 ± 0.06 ^b (0.038–0.287)
<i>LSD_{0.05}</i>	0.71 (NS)	0.117(*)	0.07 (NS)	0.01 (NS)	0.063(*)	0.025(NS)
<i>P value</i>	<.001t	0.005	<.001t	0.014 trt*t	0.001	0.037

Data are mean values ± standard error of mean; different superscript letters in the same column denote treatments that are significantly different (P<0.05). The data in parentheses are the minimum and maximum recorded for each treatment; **RT** denotes rice field treatment; P values with **t** denote time-based differences (that is, sampling days); P values with **trt*t** refer to the differences considered for interaction treatment*time.

6.3.5 Nutrients in rice field and fish pond soil

The pH, CEC, NH₄-N, TN, TP, and PO₄-P were analysed to characterise chemically the impact of integrated livestock (rabbits) and aquaculture on the soil at the bottom of the ponds as well as the soil in the rice fields. The results obtained for the start, midterm (90 days), and end (153 days) of the experiment are summarised in Figures 6.1 and 6.2. A slight increase over time in pH was observed in both the ponds stocked with one fish per m² (PT1) and those stocked with three fish per m² (PT2), with no significant difference being discerned between them (P<0.05). At the end of the experiment, the pH averaged 4.78 and 4.92 in PT1 and PT2 respectively, while the averages were 4.65 and 4.70, respectively at the start of the experiment. The CEC averaged 9.69 and 7.98 meq/100g in PT1 and PT2, respectively, and were different from one another (P<0.05). A decrease was noted in CEC, especially in the ponds stocked with the least fish, from the start of the experiment to the end.

TN concentrations were significantly higher ($P < 0.05$) in PT2 than in PT1 at the end of experiment, but the observed N increase that took place over time within each treatment was not statistically significant ($P > 0.05$). TN concentrations averaged 0.11 and 0.15% in PT1 and PT2 respectively, with a non-significant increase ($P > 0.05$) with time, from 0.09 to 0.12% and 0.11 to 0.18% in PT1 and PT2, respectively.

There were no significant differences between P nutrients (TP and phosphates), nor between the treatments, nor among treatments, over time. As recorded for TN in the fishpond soil of PT1, the concentrations of TP and phosphates were slightly higher at midterm (that is 90 days after stocking) than at the start and the end of the experiment. This was most likely the result of the fishpond water being used to irrigate the fields, as pipes were placed near the sediment-water interface at the bottom of the ponds.

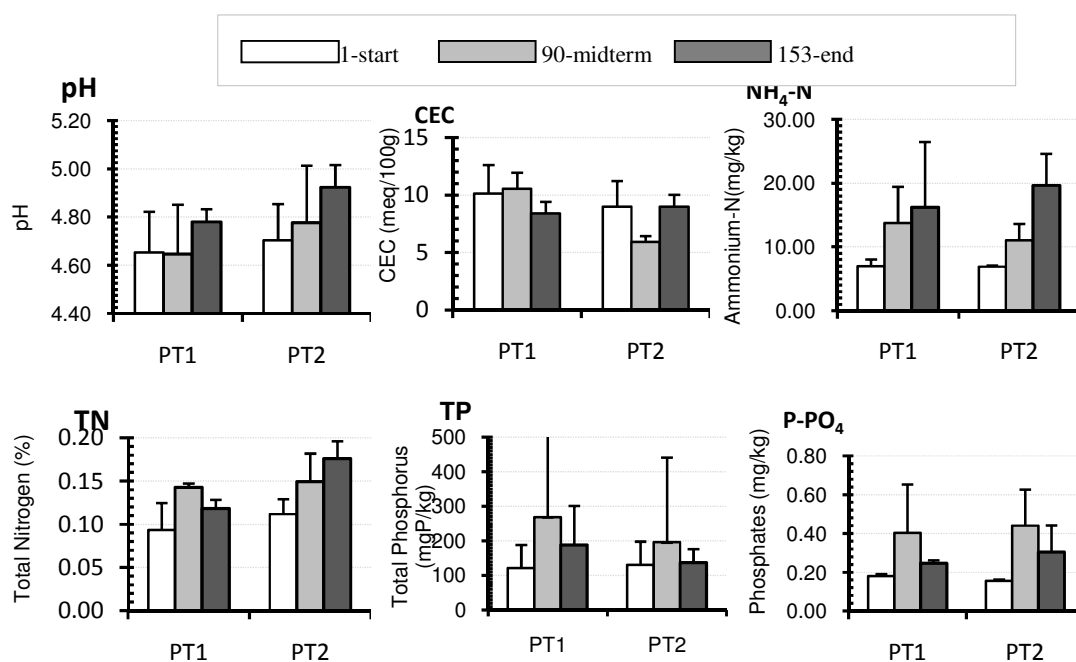


Figure 6.1: N and P in the bottom soil of fishponds that were fertilised by rabbit droppings and stocked with one fish per m^2 (PT1) and three fish per m^2 (PT2) in a rabbit–fish–rice integrated system in Rwanda. Data were collected at the start of the experiment (that is, after 1 day), at midterm (that is, after 90 days), and at the end (that is, after 153 days after transplanting) of the experiment.

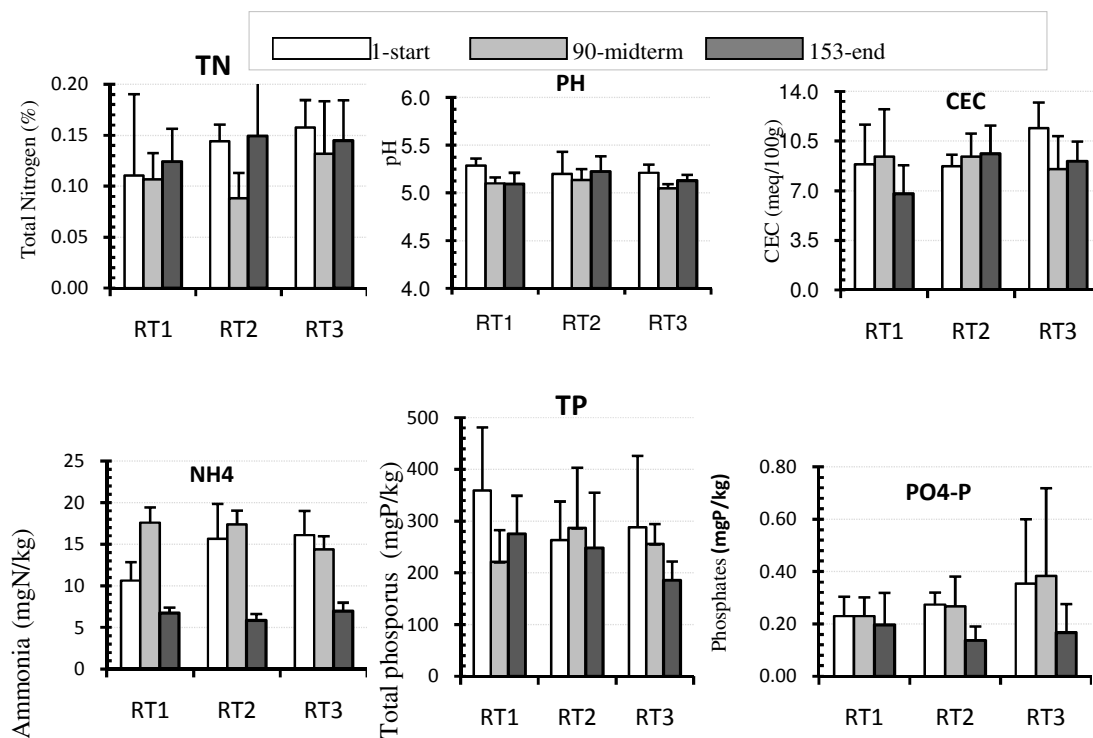


Figure 6.2: Chemical parameters in rice fields soil fertilised were as follows: RT1: chemical fertilisers (NPK and urea); RT2: effluent from fishponds stocked at one fish per m²; RT3: effluent from fishponds stocked at three fish per m². Data were collected at the start of the experiment (that is, after 1 day), at midterm (that is, after 90 days), and at the end (that is, after 153 days after transplanting) of the experiment.

Figure 6.2 shows the nutrient pattern in the rice field soil that emerged during the rabbit–fish–rice integrated system experiment. No significant changes in the parameters were observed within each treatment over the culture time. Only ammonia-nitrogen and CEC increased from the start to the end of the experiment. The treatments did not differ ($P > 0.05$) from one another at the end of the culture time for these parameters. Generally, N nutrient concentrations, TN, and ammonia (NH₄-N), decreased in the midterm point of the experiment and increased at the end of experiment in all treatments. The rice fields fertilised by effluent from highly stocked ponds (RT3) had, however, slightly higher concentrations of N nutrients than did the rice fields receiving effluent from low stocked fishponds (RT2) and the rice fields fertilised by chemical fertilisers (RT1). The mean concentrations for TN were 0.1 ± 0.05 , 0.1 ± 0.04 , and $0.1 \pm 0.04\%$ N in rice field soil for RT1, RT2, and RT3, respectively. Even though no significant differences

were observed with regard to TP and phosphates ($\text{PO}_4\text{-P}$) between the treatments, changes could be signalled within treatments over time and among treatments at the end of rice culture period.

Phosphate concentrations were higher in RT3 ($0.3 \pm 0.2 \text{ mg P.kg}^{-1}$) than in RT2 ($0.2 \pm 0.09 \text{ mg P.kg}^{-1}$) and RT1 ($0.2 \pm 0.08 \text{ mg P.kg}^{-1}$), and they decreased towards the end of the culture period. Inversely, TP was more highly concentrated in those rice fields that received NPK and urea (RT1) than in those (RT2 and RT3) fertilised by pond water effluent. TP concentrations were high at the start (359.5 ± 112 , 263.7 ± 74.77 , and $288.2 \pm 138.2 \text{ mg P.kg}^{-1}$ for RT1, RT2 and RT3 respectively), but then decreased progressively to an average of 275.8 ± 73.8 , 248.3 ± 107.1 , and $186.1 \pm 36.18 \text{ mg P.kg}^{-1}$ for RT1, RT2, and RT3, respectively at the end, with no significant differences recorded between the treatments.

6.4 Discussion

Source of nutrients in the IRFR system

The productivity of all IAA fishponds depended totally on inputs which originated mainly from on-farm and/or off-farm sources of nutrients but all external to the fishpond (Rahman *et al.*, 2004; Nhan *et al.*, 2008). Studies on the use of rabbit droppings and of the resource-flow in the IRFR system (Breine *et al.*, 1996; Van Vleet, 1997; Rukera Tabaro, 2001) have confirmed that rabbit droppings (faeces and urine) provide not only a better environment for tilapia but also a major source of nutrients on which the whole system of fish and rice production relied. The rabbit dung composition, in this study, showed that rabbit dung could be a better fertiliser than most other manure.

This study investigated the flow of nutrients (N and P) by means of their mass balance throughout the IRFR without considering a complete nutrient budget of the system. The mass balance of N and P nutrients showed that rabbit waste accounted for about 27.0% N and 79.1% of the P of the total nitrogen and phosphorus input supply. Of this, rabbit urine accounted for 20.0% N and 64.0% P of the total N and P respectively of the total fishpond inputs, thus highlighting the major role of rabbit urine in providing nutrients.

The nutrient mass balance explains effectively the nutrient flow and contribution of each resource, but is not a good estimation of nutrient budgets which normally require an accurate estimate of the volume of water being exchanged in the system. This estimation poses difficulties; Nath and Bolte (1998) reported the uncertainty and difficulty of estimating pond seepage and pond evaporation, arguing that methods based on changes in pond depth are prone to error. To avoid such errors, we opted for the nutrient mass balance.

This method was also chosen because of the difficulty in determining the exact amount of pond mud, the denitrification, and the ammonia volatilisation; in most studies these potential factors of N losses are estimated indirectly. The higher amount of nutrients contained in the influent water is due to the order of magnitude comparable to the organic resource amount as ponds are refilled after rice field irrigation by pond effluent; this confirms the success of such practices in Rwanda. The influent water provided up to 72.99% N and 20.91% P as an off-farm source of the N and P

input to the pond; these quantities may have been principally constituted of dissolved organic nitrogen (DON) from the rice and vegetable fields upstream of the fish farming station. According to [Burford *et al.* \(2003\)](#) the DON is decomposed slowly by bacteria and therefore accumulates over the rearing time, the DON was reported to be the major form of N ([Jackson *et al.*, 2003](#); [Nhan *et al.*, 2008](#)) in fishponds. Therefore, the nutrients available after decomposition of rabbit droppings by bacteria may have resulted largely from use during phytoplankton development.

Water fertilisation and nutrient distribution

The concentrations of measured variables for water quality suggested good conditions for phytoplankton and tilapia growth. The significant increase during the day for pH and dissolved oxygen confirmed good phytoplankton activity; this activity, on the one hand, removes carbon dioxide by photosynthesis and, on the other hand, enriches the water with oxygen through the same process ([Boyd, 2001b](#); [Frei and Becker, 2005a](#); [Vromant and Chau, 2005](#)). The removal of effluent to fertilise rice fields seems likely to have been the only probable reason for the fluctuation observed in TN and TP concentrations, during which N decreased mainly after the first month.

About 27% of the N and 79% of the P from the rabbit droppings were released in fishponds, fertilising the pond water at a rate of 3.98 kg N and 1.94 kg P.ha⁻¹.day⁻¹; this is a higher rate than that (1.75 kg N and 0.39 kg P.ha⁻¹.day⁻¹) reported in an integrated Nile tilapia cage-cum-pond system ([Yi *et al.*, 2003c](#)) where tilapia were fed pellet feed and waste fertilised ponds were used to raise fingerlings. This rate is comparable to that (3.71 kg.ha⁻¹.day⁻¹ N and lower than 8.06 kg.ha⁻¹.day⁻¹ P) observed in caged hybrid catfish waste fertilising open-pond Nile tilapia ([Lin and Yi, 2003](#)).

The inputs from rabbits provided a pond fertilisation rate equivalent to the application of urea and triple superphosphates (TSP) at the rate of 4 kg.ha⁻¹.day⁻¹ of N and 1 kg.ha⁻¹.day⁻¹ of P used by [Yi *et al.* \(2002\)](#) in an integrated Lotus-Tilapia experiment (2 fish.m⁻²) that resulted in a net fish yield (3345±113.4 kg.ha⁻¹.yr⁻¹), comparable to that obtained in the present study (2611 kg.ha⁻¹.yr⁻¹ for 1

fish.m⁻² and 3459 kg.ha⁻¹.yr⁻¹ for 3 fish.m⁻²). The rabbit droppings thus raised substantially the TN and TP concentrations of pond water from 0.21 to 3.2 mg.l⁻¹ of TN and 0.01 to 0.7 mg.l⁻¹ of TP.

Supplement material to that from rabbit waste might be canal water, fish waste, plankton die-off, and other external unaccounted sources such as levee and watershed erosion, small leaves from rabbit hutches, and leaves blown into the pond by wind (Piedrahita, 2003; Yuvanatemiya and Boyd, 2006). Excretion of about 59–72% of the N and 60–62% of the P constituents in the feed are reported for tilapia (Siddiqui and Al-Harbi, 1999, cited by Piedrahita, 2003). Yi *et al.* (2003b) observed that covering the pond edge substantially reduced nutrients in pond and concluded that run-off from the pond dyke was the major source of turbidity in the fishpond.

The effluent from the fertilised pond in this study held high amounts of TN (about 19175–18135 kg N.ha⁻¹) and TP (3510–4225 kg P.ha⁻¹) following their respective fish stocking rates (1 & 3 fish per m²). When used to irrigate rice fields, these effluents provided the rice fields with about thirteen times the amount of N (1478 kg.ha⁻¹ TN) and more than twenty-six times (133 kg.ha⁻¹ TP) of P obtained in treatment with inorganic fertilisers (NPK and urea). The role of rabbit droppings as pond fertiliser was thus clearly highlighted and the results showed that it was not necessarily dependent on fish stocking density. The reported study was limited in that only harvested fish, rice grain, and rice straw were assessed for N and P as major nutrient output of the integrated system.

N and P recovered by harvested products

The assessment of N and P mass balance showed that with a low fish stocking rate, Nile tilapia recovered lower N and P from inputs than with a high fish stocking rate; this was probably due to the amount of fish waste in these ponds which logically surpassed that present in ponds with a low stocking rate. In low stocking rate ponds (1 fish.m⁻²), Nile tilapia recovered 18.5% N and 16.9% P of the TN and TP of the rabbit droppings inputs, while this recovery was only of 4.9% N and 13.3% P of the total N and total P inputs, including that of the inflow canal water.

In higher stocking density rate ponds (3 fish.m⁻²), the fish recovered more (37.6% N and 34.3% P) of the total N and total P of the rabbit droppings input; including the canal water that refilled ponds, this was only 10.2% N and 27.13% P of the total inputs. Whatever the considered source

of input, these nutrients recovery rates were higher than many recovered rates reported in various studies (Table 6.4).

Table 6.4. Nutrient recovery rates by Nile tilapia for various rearing systems

Rearing Integrated System	Input origin	Recovery rates		Studies
		TN (%)	TP (%)	
Intensive and recirculation tank for tilapia aquaculture	Tank wastes	21-22	18.8	Siddiqui& Al-Harbi (1999) in Piedrahita(2003)
Intensive Aquaculture in tilapia	Various feed	47.73	18.18	Schneider <i>et al.</i> (2005)
Tilapia-cum-tilapia	Caged tilapia waste	20.52	27.98	Lin and Yi (2003)
Hybrid catfish-cum-tilapia	Caged catfish waste	12.75	14.27	Diana (1995) in Lin and Yi (2003)
Domestic wastewater-tilapia	Treated sewage	13.00	--	El-Shafai <i>et al.</i> (2007a)
Chicken-cum-Nile tilapia	Chicken manure	15.5 - 21	--	Schroeder <i>et al.</i> 2003
Rabbit–fish–rice	Rabbit droppings	37.6	34.3	This study

The probable explanation for the differences shown in various recovery rates relies on how quickly each source makes nutrients available to the fish. It is known that when nutrients from feeds are directly used by fish, the recovery rate is higher than when fertilisers are used. Tacon *et al.* (1995), cited by El-Shafai *et al.* (2007a) found that supplementing feed in semi-intensive aquaculture farms improved N recovery, ranging from 5% to 25%, in fish. It can be argued that rabbit droppings must be better used by fishponds than many other inputs thus ensure a better environment for Nile tilapia growth.

The rice field component of the system received fertilised pond effluent as organic input for rice growth. The results showed that rice grain accounted for a lower percentage of input in fields fertilised with effluent (0.44–0.50% N and 0.22–0.25 P of the total N and P of the effluent input) than in fields treated with NPK and urea (6.11% N and 6.54% P of the total N and P inputs). The rice straw in fields fertilised by effluents accounted for 0.77–0.79% N and 0.71–0.88% P, while it accounted for 10.79% N and 23.24% P of the total N and total P inputs. The differences obtained here seem logically to be due to the order of magnitude of each source of input. The amount of nutrients supplied in the effluent was high and therefore remained in the soil, the seepage, and contributed to weed growth during the farming period.

Nutrients in pond sediment, rice field soil, and seepage water

Nutrient mass losses were difficult to measure precisely because the amount of sediment, infiltrated water, and nutrients accumulated in the rice fields were not quantified but only their concentrations in water and sediment assessed. Changes in sediment concentrations of P and phosphates followed the activity applied in the fishponds.

Normally P is strongly adsorbed by pond soil directly from pond water (Knud-Hansen *et al.*, 1998; Boyd, 2001b), while N is lost primarily through ammonia volatilisation and denitrification (Gross *et al.*, 1999). Munsiri *et al.* (1995) in Yuvanatemiya and Boyd (2006) stated that organic matter, N, P, and TP in pond bottom soil accumulates strongly in the upper 10–20 cm of sediment as a result of the fertilisation process due to microbial activity.

In the present study, TN and ammonia nitrogen, as well as TP and phosphates, increased up to midterm (i.e. 90 days) but thereafter, except for ammonia nitrogen, decreased until the end of the experiment. The observed decrease in P and TN was most likely due to adult fish movement and the various factors causing waves (for example, pressure from the pipe sucking water) which disturb the sediment–water interface, thereby allowing re-suspension of nutrients sucked by the pipe to irrigate the rice field.

Overall, no significant changes in nutrient concentrations were observed in the rice field soil, neither among treatments nor over time, and this demonstrated that nutrients were used by growing rice at almost the same rate in inorganic or effluent fertilised fields. The ammonia, TP, and PO₄-P pattern in rice field soil showed higher concentrations at the beginning of the experiment as a result of fertiliser application and irrigation by pond effluent, but all these nutrients decreased at the end of the experiment. These observations agree with Vromant and Chau (2005) whose findings identified an increase of nutrients in the soil during the first 15 days after transplanting (DAT). The decrease in N and P at the end of experiment was probably due to the nutrient uptake by the rice in the growing phase, caused by the strong nitrification processes in the upper layer of the soil (De Dautta *et al.*, 1985, in Vromant and Chau, 2005).

The present integrated system was designed in such a way that all effluent used for irrigation could filtrate through rice soil before it reached the environment. Lower concentrations, but not significant, were observed for TN, TP, and phosphates, while nitrates decreased significantly and ammonia increased in the water that reached the under layer of soil. N forms were higher in seepage water than P forms, suggesting that microbial activities on N were more intense at the soil surface and in the pipes in which ammonia concentration increased and surpassed that in effluent water.

The seepage water accounted for only between 80 and 88% of TN and TP of the effluent that entered the rice field, between 29 and 40% of the soluble phosphates, and up to 6.0% of the nitrates of the effluents. This observation suggests that nitrates and soluble phosphates were the nutrients most used by the growing rice.

6.5 Conclusions

About 27% N and 79% P in pond water were attributable to rabbit droppings (faeces and urine). Rabbit droppings provided a fertilisation rate of 3.98 kg N and 1.94 kg P.ha⁻¹.day⁻¹, leading to fish yields comparable to those obtained from using urea and TSP at a rate of 4 kg N and 1 kg P.ha⁻¹.yr⁻¹, yielding 3 344.6 kg.ha⁻¹.yr⁻¹ for 2 fish.m⁻² stocking density of male Nile tilapia in an earthen pond.

Fish recovered about 18.5–37.6% N and 16.9–34.3% P of the TN and TP in rabbit dropping input to the pond. The relatively large amount of N and P that passed through pond water made it especially appropriate for rice fertilisation and could replace totally the inorganic fertilisers used in common practice in the culture of rice. The re-use of tilapia pond effluent, captured from the bottom of the pond, allowed the recycling of the large amount of N and P by providing the growing rice with required nutrients at a high rate (118.5–125.3 kg N and 22.9–21.2 kg P.ha⁻¹.day⁻¹).

The lack of these nutrients, especially N, is the most limiting factor in irrigated rice fields (De Datta *et al.*, 1988, in Vromant and Chau, 2005). In this way, in an integrated pond effluent and rice culture system, a large amount of N accumulated in the rice field, making the soil able to be better used for a demanding rotated crop. This integrated farming is environmentally friendly and sustainable, thus appropriate for resource-poor farmers in developing countries, such as Rwanda, as it recycles nutrients, thereby reducing the investment costs and the negative environmental impacts of aquaculture.

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7. CHAPTER SEVEN: Performance and profitability of an Integrated Agriculture-Aquaculture System: Rabbit–Fish–Rice System Experimented in Rwanda

The following article is based on the chapter 7:

Rukera Tabaro, S., Mutanga, O., and Micha, J.-C. n.d. (submitted). Performance and Profitability of an Integrated Agriculture-Aquaculture System: Rabbit–Fish–Rice System in Rwanda. *Aquaculture Economics and Management*.

Abstract

This study was carried out to evaluate the growth and yield performance and the profitability of rabbits, Nile tilapia, and rice paddy under an integrated rabbit–fish–rice (IRFR) system in tropical semi-intensive farming. The experiment allowed the rearing of rabbits over six ponds, three of which were stocked with one fish per m² and three others with three fish per m², and nine rice fields, of which three received inorganic fertilisers and six received effluents. The rabbits demonstrated potential to adapt in humid areas as their individual weights increased from 800 to 1860 g in 101 days with production of 1.4 t.ha⁻¹ of pond. Fish yields of 953 and 1939 kg.ha⁻¹ for 1 and 3 fish.m⁻² respectively (which are equivalent to 2.0 and 3.3 t.ha⁻¹.yr⁻¹) were generated without supplemental feed. The reuse of this wastewater in rice irrigation improved rice production up to 5.87±0.2 t.ha⁻¹.crop⁻¹ of rice paddy and 9.9±0.1 t.ha⁻¹.crop⁻¹ of rice straw, and these yields were not significantly different from the rice alone yield (5.79 t.ha⁻¹) treated with inorganic fertilisers. The net return increased up to 596.9% (US\$30–208) in rabbit–fish–rice with 3 fish.m⁻² over the net return in rice monoculture, while it increased by 57.0% (US\$132–208) over the rabbit–fish–rice with one fish.m⁻². However, while net return increased with increasing stocking density, the profitability (benefit-cost ratio) decreased, suggesting that a farmer should go for the full integration, as investing more provides a guarantee of higher net returns. We conclude that, as a whole, the integrated rabbit–fish–rice system works well and can be promoted for optimum resources use, better income generation, and environmentally friendly productions.

Keywords: Integrated farming system, rabbit–fish–rice system, wastewater reuse, Tilapia yield performance, cost-benefit analysis.

7.1 Introduction

Nile tilapia *Oreochromis niloticus* L., has for many years been the fish species most cultivated by Rwandese fish farmers. However, its profitability is still low due to weak production, resulting mainly from insufficient feeding because the by-products are scarce in Rwanda. For this reason, the Integrated Aquaculture Agriculture (IAA) system could be a way to improve Rwandese fish farmers' production and earnings. Until now, research on the use of rabbit dung in aquaculture has interested few scientists and direct integration of rabbit to fish production remains scarce (Breine *et al.*, 1996).

The rare works conducted in this line to date include the application of rabbit dung either as fertiliser for tilapia ponds or tanks (Franco, 1991; Breine *et al.*, 1996; Nguenga *et al.*, 1997) or as feed resource directly consumed by catfish (*Heterobranchus longifilis*) (Breine *et al.*, 1996). Very few trials are reported in the literature on the integration of rabbit farming in aquaculture in the style of IAA as is known for chicken, ducks and pigs, where wastes are transferred directly from one farming sub-unit to another without human intervention. This IAA style also allows one to exploit the richness of rabbit urine, which is reported to contain about 50% nitrogen, 6% phosphorus, and 60% potassium of the totals found in manure. Moreover, nutrients in urine are more readily available to pond phytoplankton than are those in solid dung.

The use of animal manure from chickens, geese and ducks has been successful in Asia and Europe (Sarvala, 1993). Tilapia pond production in the Philippines, Rwanda and Cameroon range from 4.7 to 6.1 t.ha⁻¹.yr⁻¹ in ponds fertilised with pigs, chicken, ducks, and manure supplemented by bran (rice or wheat) (Moehl *et al.*, 1988; Breine *et al.*, 1996; Nguenga *et al.*, 1997; Little and Edwards, 2001). On the other hand, when rabbits with a density of 10-15 rabbits/are and being fed on a supplement of 30% crude protein pellet were raised over tilapia ponds, the net fish yield averaged 6,1 t.ha⁻¹.yr⁻¹ (Van Vleet, 1997). Lower production have been reported when rabbits were fed on grass only: 1.6–3.3 t.ha⁻¹.yr⁻¹ yielded for rabbit stocked at 4–8 rabbits.are⁻¹ (that is 400–800 rabbits.ha⁻¹ of pond (Matsiko, 2004). While the IAA system has a long tradition in many Asian countries (Gupta *et al.*, 1998; Xiuzhen, 2003; Halwart and Gupta, 2004; Nhan *et al.*, 2007; Karim *et al.*, 2011), in Africa the IAA system is only developed in Egypt and, as is the case in the majority of Asian countries, is dominated by the rice-fish system. Better rice equivalent yields

(REY) are often found in rice-fish culture (Lightfoot *et al.*, 1994; Mohanty *et al.*, 2004) and rice paddy yields range between 1.5 and 1.8 t.ha⁻¹.crop⁻¹ in rice alone, whereas it is 1.6–3.7 t.ha⁻¹.crop⁻¹ in integrated rice–fish (Haroon and Pittman, 1997).

During the last eight years, the rice farm area in Rwanda has increased from 4750 ha in 2001 (MINAGRI, 2004, in Kayiranga, 2006) to 15650 ha in 2008 (SHER *et al.*, 2008), thereby increasing the paddy production from 60000 tonnes in 2005 to 82000 tonnes in 2008 (NISR, 2009). It was the country's relief, the progress made in rice culture, and the predisposition of Rwandan farmers to easily integrate fish and rice through irrigation that prompted the present study.

The present article aimed at investigating the performance of rabbit, fish Nile tilapia and rice production in integrated fish farming where fish and rice cultures are linked through an irrigation system. The paper focuses on the fertilisation of various sub-units of the integrated system, adding rabbits as a source of fertilisers to the fishponds, which in turn serve as an irrigation reservoir to constantly fertilise the rice field. The study also provides a framework that highlights the economic profitability of applying the rabbit density found as optimum for fish production in this IRFR system using Nile tilapia.

7.2 Materials and Methods

7.2.1 Rabbit rearing

A local strain of the rabbit *Oryctolagus* was housed in hutches built over the fishponds so that the rabbits wastes were directly dropped into the fishponds. Each hutch was comprised of four cages, and these cages were all 1 m² in surface and between 0.7 and 1 m in height. Each cage contained 4 rabbits, making a total of 48 rabbits per 4 are of pond, meaning a stocking density of 1200 rabbits per hectare of pond, since our earlier study showed this to be the optimal density (Chapter 5).

The rabbits (600–800 g mean weight) were placed into their hutches one week before the ponds were stocked with fish and two weeks before the rice was transplanted into the adjoining fields.

The rabbits were fed various grass cuts from SPIR's surroundings. During the first month of the experiment the grass ration was supplemented with handmade pellets formulated in the SPIR to ensure the rabbits adapted well to the new environment.

During the experiment, a sample of twelve rabbits per fishpond (meaning 72 rabbits were weighed for the whole population) was taken out of the hutches every fortnight and each of the twelve rabbits was individually weighed using an electronic balance (Mettler balance, accuracy: 0.1 g). This was done so as to monitor the growth of the rabbits. The collective data generated by the rabbit sample allowed calculating the daily growth gain ($\text{g}\cdot\text{day}^{-1}$), the survival rate (%), and the net rabbit production ($\text{t}\cdot\text{ha}^{-1}$ of pond).

7.2.2 Rice farming management

Nine experimental rice fields were developed for the study experiment from a two-year fallow plot of land previously used for vegetable production. Rice fields had a 90 m^2 surface area ($0.9 \times 10 \text{ m}$) each, and each one linked to a four-acre fishpond through a PVC pipe ($90 \text{ mm } \varnothing$) placed at the bottom of the pond since nutrients are expected to be more concentrated at the bottom (Sonnenholzner and Boyd, 2000) than in the water column (Figure 3.2).

Three treatments took place in the rice fields: (1) rice treatment 1 (RT1), where three of the nine rice fields were fertilised by chemical fertilisers (NPK: 17:17:17 and Urea 45%N); (2) rice treatment 2 (RT2), where three of the nine rice fields were fertilised by the effluent from the fishponds stocked with one fish per m^2 (*ponds of PT1*); and rice treatment 3 (RT3), which received effluent from the fishponds stocked with three fish per m^2 (*ponds of PT2*).

7.2.2.1 Rice farming

The rice nursery beds as well as the rice fields were manually ploughed, the soil was levelled, and they were then flooded with either pond effluent or water from the canal for two days in accordance with the recommendations of the Rwandan Institute for Agronomic Research / Rice programme (ISAR) for the *Yuni yin4* variety. The rice seedlings were transplanted into the fields at a spacing of $20 \times 20 \text{ cm}$ on 25 August 2010, three weeks after the seeds had developed in the

rice nursery. The water level was lowered for the planting day, and then increased by 5 cm two days later, eventually being brought up to 15 cm as the rice grew up.

7.2.2.2 Application of fertilisers

NPK (17:17:17) and urea (45% N) were applied in accordance with the sub-optimal rate advocated by [Vromant and Chau \(2005\)](#). NPK was applied twice at 200 kg.ha⁻¹ two days after transplanting (DAT), and urea (45% N) was applied once 100 kg.ha⁻¹ at 15 DAT after the first weeding. The second application of fertilisers (NPK and urea at the same rate as before) was done at 45 DAT so as to stimulate the rice panicles in the rice fields designated for RT1 and irrigated by water from the canal. The irrigation for the rice fields of RT2 and RT3 took place twice a day (at 07h00 and 17h00) so as to maintain a water level of 15 cm in height. The fields undergoing RT1 were irrigated with water from the canal. Dimethoate was applied once (40 DAT) at a rate of 100 cc/100 l/ha of rice fields so as to control the flies.

7.2.2.3 Rice data collection and harvesting

Data concerning straw height and rice tillering were recorded fortnightly. The straw height was measured using a 50 cm graduated classic ruler and the number of tillers was counted manually. The data from a sample of ten plants per rice field, which were chosen randomly along a “W” pathway drawn into each rice plot, was collected at the beginning of the experiment and indicated by dry sticks numbered from 1 to 10 that were sunk near each plant. The data collection process was interrupted at 56 DAT (that is when the first panicle appeared in the fields) in order to avoid damaging the panicles, and the irrigation ceased on 29 December 2009, which is when the rice was estimated to be mature enough.

At harvest, data concerning rice production was recorded in addition to the data concerning rice growth. Rice remnant biomass and the total yield of rice paddy per field were weighed using a commercial balance (with a precision of 0.1 kg). This data enabled us to calculate the net rice production and the straw production, both expressed in tonnes per hectare per year (t.ha⁻¹.yr⁻¹), as well as the net yield, expressed in tonnes per hectare per crop (t.ha⁻¹). A laboratory balance

Mettler (precision: 0.1 g) was used to measure the weight of 1000 paddy grains in order to assess the quality of the rice grains. Tillers holding panicles were counted per rice field and expressed as a percentage per m². Panicle length was also measured using a 50 cm graduated classic ruler.

7.2.3 Fish culture and data collection

A week after the rabbit hutches were populated and the ponds filled with water, male juveniles of Nile tilapia were stocked in the ponds, thereby determining two different treatments. Three ponds were stocked with one fish per m² (PT1: 1 fish.m⁻²), and the other three received three fish per m² each (PT2: 3 fish.m⁻²), but all were fertilised with rabbit droppings (dung and urine) that fell directly from the rabbits in the suspended hutches.

Thirty-five fish from each of the six ponds were used as a sample. Each fish was measured lengthwise and weighed at stocking time. These measurements were repeated every fortnight as well as at the end of the experiment. In addition to the fortnightly data, the whole crop was weighed at harvest time. All the collected data allowed for the determination of: (1) the fish growth, which included their final mean weight, specific growth rate (SGR in %·day⁻¹), and daily weight gain (DWG in g·day⁻¹), as well as (2) details about their production, which included gross yield (kg·are⁻¹ also expressed in kg·ha⁻¹), net fish yield (NFY: kg·are⁻¹·yr⁻¹ and expressed in kg·ha⁻¹·yr⁻¹), and fish survival rate (SR: %).

7.2.4 Profitability analysis of the integrated rabbit–fish–rice system

An economic analysis was conducted for each of the components of the integrated rabbit–fish–rice system and for the integrated system as a whole after an economic evaluation of the treatments involved in the study. All the data and the results were based on a 4 are (400 m²) fishpond and 90 m² rice field. The profitability was assessed based on input costs (fixed costs: FC, and variable costs: VC) and output costs (Gross return) considering that all productions could be sold. Table 7.3 distinguishes costs that were used as fixed from those considered as variable costs and profitability indicators. These profitability indicators were performed by calculations of

the return above variable costs (RAVC), the net return (NR) based on the total output value named gross return (GR), and the total input costs (TC). The following equations were then used:

$$\text{Total costs } TC = FC + VC; \text{ RAVC} = GR - VC;$$

$$\text{NR} = GR - TC, \text{ and the profitability or benefit-cost ratio } BCR = \text{NR} / TC$$

The prices of all articles corresponded to Rwanda's (Butare) wholesale market prices of 2010 and are expressed in US\$ (US\$1 = 585 Rwanda francs (Rwf) during the first trimester of 2010). The wholesale price in Butare per kg of fish or rabbit was 2000 Rwf.

7.2.5 Statistical analysis

The mean values for all the variables were compared using a two-way ANOVA) for parameters changing over time, especially rabbit, fish and rice growth parameters. ANOVA I was applied for fish and rice production parameters as well as for cost-benefit indicators in the economic analysis of the integrated system. Variables that were measured repeatedly, such as rice tillering and straw height, were analysed by ANOVA for repeated measurements that consider successive times data. Significant differences among the treatments as shown by ANOVA were further tested using the least significant differences of means at a 5% level ($LSD_{0.05}$). Possible relationships between the parameters were highlighted through regressions and correlations analysis using GenStat statistical software (GenStat 12.1 Ed[®], 2009 – VSN International Ltd), which was also used for ANOVA.

7.3 Results

7.3.1 Rabbit growth

Rabbit mean weight increased from 821.03 g to 1861.18 g, allowing the rabbit biomass over a 4 are (400 m²) fishpond to increase from 32.841 kg to 54.455 kg during the 101day rabbit monitoring period when they were only fed grass *ad libitum*. The yield made on rabbit averaged 54.455 kg per fishpond (400 m²), which makes 1.4 tonnes per hectare of pond. The rabbits excreted an average of 0.85 kg of faeces and 1.69 litres of urine per hectare and per day, which fertilised the pond water continuously. The water quality parameters as well as the nutrient concentration in all the ponds were always within the acceptable ranges for aquaculture during the entire period of the experiment (Chapter 6).

7.3.2 Nile tilapia growth and production

Figure 7.1 shows that fish mean weight was weakly correlated to chlorophyll-*a* ($r=0.243$, $n=48$). The highest fish growth was observed in the treatment that showed a decreasing concentration of chlorophyll-*a* over time, and vice versa. Fishponds stocked at 1 fish.m⁻²(PT1) grew with a SGR (1.03% .day⁻¹) and a DWG (0.64 g.day⁻¹) significantly higher ($P<0.001$) than those recorded for PT2, which was the treatment where fish were stocked at a rate of three fish.m⁻².

By contrast, production performance was better in PT2 than in PT1. Ponds stocked with 3 fish.m⁻² (PT2) showed a significantly higher ($P = 0.007$) net fish production (NFY) (34.6±2.8 kg.are⁻¹.yr⁻¹) than did those undergoing PT1 (21.6±3.5 kg.are⁻¹.yr⁻¹). Yield and total biomasses also differed significantly ($P<0.01$) between the different treatments. More highly stocked fishponds had a significantly higher fish yield and biomass than did the ponds that were stocked with fewer fish (PT1). Pond treatments (fish stocking rates) did not affect the fish survival rates in this study ($P>0.05$, Table 7.1).

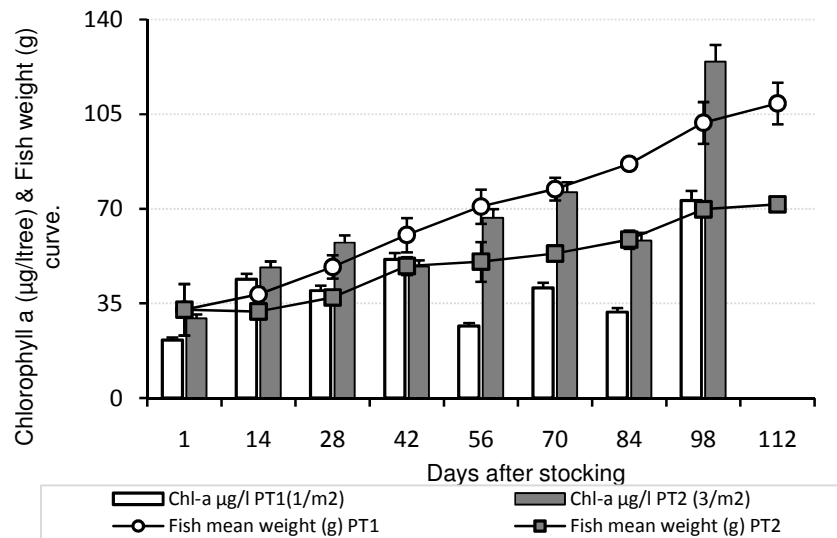


Figure 7.1: Trends in Nile tilapia mean weight stocked at one (*lines with white spots*) and three (*line with black squares*) fish.m⁻² in relation with that of chlorophyll-a (bars) in a rabbit–fish–rice integration system. (The fish ponds were fertilised with rabbit droppings and the effluent from the ponds served to simultaneously irrigate the rice fields.)

Table 7.1: Growth and production performance of Nile tilapia stocked at 1 and 3 fish.m⁻² in a rabbit–fish–rice integration system

Growth performance		Treatments			
		PT1	PT2	LSD _{0.05}	P _{value}
Initial mean weight	g.fish ⁻¹	32.7 ± 9.50	32.7 ± 9.50		
Final mean weight	g.fish ⁻¹	104.3 ± 4.21 ^a	70.7 ± 1.65 ^b	7.25	<.001
Specific growth rate	% .day ⁻¹	1.0 ± 0.04 ^a	0.7 ± 0.02 ^b	0.06	<.001
Daily weight gain	g.day ⁻¹	0.6 ± 0.04 ^a	0.3 ± 0.01 ^b	0.06	<.001
Survival rate	%	88.5 ± 14.9 ^a	89.9 ± 4.40 ^a	24.91	0.94
Total biomass	kg	38.1 ± 6.20 ^a	77.6 ± 5.16 ^b	12.93	<.001
Yield	kg.ha ⁻¹	9.5 ± 1.55 ^a	19.4 ± 1.29 ^b	3.23	<.001
Net fish production	kg.ha ⁻¹ .yr ⁻¹	21.6 ± 3.53 ^a	34.6 ± 2.79 ^b	7.2	0.007

PT1: Pond treatment with 1 fish.m⁻²; **PT2:** Pond treatment with 3 fish.m⁻²; **g.day⁻¹:** gram per day; **kg. are⁻¹.yr⁻¹:** kilogram per are (100 m²) per year. Values are means ± SD of three fish ponds for each treatment. Different superscript letters within the same row denote statistically significant differences (P<0.05). (The fish ponds were fertilised with rabbit droppings and the effluent from the ponds served to simultaneously irrigate the rice fields).

7.3.3 Rice growth and production

The rice fields were fertilised with effluent from the fishponds, which were fertilised beforehand with rabbit droppings and stocked with 1 fish.m⁻² (RT2) and 3 fish.m⁻² (RT3). Inorganic fertilisers (NPK 17:17:17 and urea) were used in RT1.

The rice yields reported here are for filled rice paddy grain, as the unfilled grains were removed from the harvest during drying and other post-harvest treatments (Table 7.2). The paddy yield variation range was 4.9–6.4 t.ha⁻¹ corresponding to a production range of 12.5–16.0 t.ha⁻¹.yr⁻¹, with the highest mean net yield being recorded for RT3 (5.8 ± 0.24 t.ha⁻¹.crop⁻¹ or 14.8 ± 1.5 t.ha⁻¹.yr⁻¹ production), but the RT3's yield was not significantly higher than the paddy yields in RT1 and in RT2.

Table 7.2: Rice production parameters (means ± std error) in rice fields fertilised by fish pond effluent from ponds stocked with one and three fish per m² (RT2 and RT3) compared with those fields that were chemically fertilised (RT1)

Parameters	Unit	Treatments			
		RT1	RT2	RT3	LSD _{0.05}
#Paddy net yield (DW)	t.ha ⁻¹ .yr ⁻¹	14.6 ± 0.88 ^a	13.7 ± 0.64 ^a	14.8 ± 0.87 ^a	2.78 NS
#Paddy yield (DW)	t.ha ⁻¹ .crop ⁻¹	5.8 ± 0.32 ^a	5.4 ± 0.20 ^a	5.9 ± 0.24 ^a	NS
#Rice straw yield (FW)	t.ha ⁻¹ .crop ⁻¹	10.8 ± 0.32 ^a	10.0 ± 0.13 ^a	9.7 ± 0.91 ^a	NS
Tillers with panicles	%	89.1 ± 7.8 ^a	92.4 ± 5.2 ^a	95.4 ± 1.8 ^a	10.16 NS
Panicle length	cm	19.6 ± 0.53 ^a	17.7 ± 0.29 ^b	18.4 ± 0.24 ^b	0.9 *
Grain weight (10 ³ grains)	g	29.0 ± 0.55 ^a	28.9 ± 0.99 ^a	28.9 ± 0.95 ^a	2.55 NS
Missing plant at harvest		35.3 ± 3.18 ^a	52.7 ± 17.4 ^a	41.3 ± 7.13 ^a	38.2 NS

The entire paddy yield of the plot (90 m²) was weighed after repeated sun-drying while the straw biomass was weighed directly in the field at harvest time while still fresh. For each mean value ± standard error, the indices within a row with the same superscript letter are not significantly different at the 0.05 level. **DW** and **FW** denote dry and fresh weights respectively.

The rice straw yield was lower in the rice fields that received effluents (RT2 and RT3) than in the rice fields that were fertilised with chemical fertilisers (RT1), but the difference was not significant (P>0.05).

The quality of the filled grain was not affected by the type of fertilisation; the weight of filled rice paddy grain ranged from 27.4 to 30.8 g per 1000 grains. Rice fields fertilised with NPK and urea (RT1) showed the fewest tillers with panicles, but the figures did not differ significantly from those produced by rice fields treated with pond effluent (RT2 and RT3).

Panicles of 19.6 cm mean length were found in the fields fertilised by NPK and urea (RT1). These were significantly longer ($P < 0.001$) than the mean lengths of the panicles found in the fields undergoing RT2 and RT3, which had panicles of 17.7 and 18.4 cm respectively (Table 7.3). The lowest mean number of dead plants (35.3 ± 3.18) was counted in the rice fields fertilised by chemical fertilisers, but this number did not differ significantly ($P > 0.05$) from the number of dead plants that were recorded in the fields undergoing RT2 and RT3.

7.3.4 Economic analysis

The cost-benefit analysis of the integrated rabbit–fish–rice system was carried out using the inputs and output costs based on the experimental time (112 days of fish culture, 152 days of rice culture) and the unit size of the land (i.e. 4 are (400 m²) of fishpond and 90 m² of rice fields). The profitability of the rice–fish culture is undeniable, as reported by a number of researchers ([Frei and Becker, 2005c](#)), but this study's integration style is different as the researchers report on fish cultured into rice fields.

Nevertheless, the net return made in integrated rabbit–fish–rice as a whole during the present study was significantly greater ($P < 0.001$) than that obtained in the components separately. The total investment costs were obviously higher in the integrated system (Table 7.3) than in the components as the needs were different and specifically related to each component but were nonetheless merged for the integration.

Considering the rabbit–fish part of the integration, the study also showed that total costs and gross and net returns were directly related to the fish stocking density. PT2 with 3 fish.m⁻² doubled the profitability indicators realised by PT1, for which the stocking density was one fish per m² (that is US\$ 130–265 and US\$ 82–148 respectively for GR and NR). However, when the pond effluent was used to fertilise the rice fields, an increase of up to 14.8% of the NR

comparable to that obtained when the rice was fertilised with NPK and urea was noted (*result not presented here*). When the rabbit–fish system was integrated into the rice culture, the overall system’s NR increased over the rice alone (RA) by 343.9–596.9%, and the RAVC by 552.0–796.6% over the one obtained for rice alone, dependent on fish density.

Table 7.3: Cost-benefit analysis for the integrated rabbit–fish–rice system as a whole (US\$ based on experimental area of 400 m² fish pond and 90 m² rice field)

	RT1 (RA)	RT2 (IRFR-1f)	RT3 (IRFR-3f)	Lsd _{0.05} ANOVA	
Fixed costs					
Rabbit hutches	--	55.38	55.38	--	--
Fishpond	--	12.35	12.35	--	--
Land rental	1.03	1.03	1.03	--	--
Variable costs					
Young rabbit	--	32.93	32.93	--	--
Fingerlings	--	34.19	102.57	--	--
Rice seeds	0.26	0.26	0.26	--	--
Inorganic fertilisers	3.60	--	--	--	--
Pesticides	0.26	0.55	0.55	--	--
Labour (<i>Rabbit, fish, rice</i>)	9.83	86.76	86.76		
Total cost (TC)	14.7 ± 0.0	223.2 ± 0.0	291.5 ± 0.0	--	--
Gross return (GR)	44.5 ± 4.6 ^a	355.5 ± 16.5 ^b	499.7 ± 21.3 ^c	15.8	***
Return above VC	30.9 ± 4.6 ^a	201.1 ± 16.5 ^b	276.6 ± 21.3 ^c	31.5	***
Net return (NR)	29.8 ± 4.6 ^a	132.4 ± 16.5 ^b	207.8 ± 21.3 ^c	31.5	***
¹ Profitability (BCR)	2.0 ± 0.32 ^a	0.6 ± 0.48 ^b	0.7 ± 0.56 ^c	0.38	***

¹Profitability is a ratio of the net return over total expenses. It is the benefit cost ratio (BCR). All costs are in US\$ as obtained per a 400m² fish pond as unit for rabbit and fish, and per 90m² for rice field. **RA** represents rice alone (fertilised by NPK and urea). **IRFR-1f**: integrated rabbit–fish–rice in which ponds are stocked at 1 fish.m⁻². **IRFR-3f**: rabbit–fish–rice where ponds are stocked at 3 fish.m⁻². ***: P<0.001 statistically high difference among treatments.

7.4 Discussion

Factors affecting fish performance, like manure quantity, quality and use, as well as the effect of manuring rate and frequency on fish growth have been studied for the direct use of chicken, ducks, pigs and cows in aquaculture (Van Horn, 1998; Yi and Lin, 2000a; Little and Edwards, 2003; Yi *et al.*, 2008), but not yet for rabbits. The present study investigated the performance of rabbits reared over fishpond in wetland, Nile tilapia, and rice productions, all of which were combined in an integrated system where: (1) wastes from the rabbits fertilised fishpond water so as to allow tilapia growth; and (2) the pond effluent irrigated and fertilised rice fields for rice growth while also preventing any environmental pollution from that same wastewater. The study also analysed the costs and benefits of the complete system compared to a stand-alone rice production using the inorganic fertilisers.

Rabbit production in humid area

Integrating rabbits with fish is always delicate as the preferred environment for fish is dissimilar to the preferred environment for rabbits. The rabbits' growth performance was assessed according to the final mean weight, the daily weight gain, and the produced rabbit biomass (expressed as yield in $\text{kg}\cdot\text{ha}^{-1}$ of pond).

The humid environment did not prevent the rabbits from performing well and increasing in mean weight by 46.85% (from 726.72 ± 10.3 to 1364.07 ± 38.3 $\text{g}\cdot\text{rabbit}^{-1}$) during the 101 days of fortnightly weight measurements for rabbits fed grass only. This change recorded a production of 637.4 kg of rabbit per hectare of pond, equivalent to 7.3 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{day}^{-1}$. The recorded growth rate (6.31 to 15.96 $\text{g}\cdot\text{day}^{-1}$ for the sixth fortnight) was low, but was still close to the general growth rate range for rabbits (10 to 20 $\text{g}\cdot\text{day}^{-1}$) found in tropical regions (Samkol and Lukefahr, 2008).

The mixed species of grass supplied to the rabbits in this experiment allowed for better growth performances (weight gain) than did those (2.27 or 5.72 $\text{g}\cdot\text{day}^{-1}$) obtained after feeding rabbit with mulberry leaves or concentrates respectively (Bamikole *et al.*, 2005). Researchers using other various feed resources reported reasonably higher growth rates (21.1 - ... - 31.4 $\text{g}\cdot\text{day}^{-1}$) when using molasses blocks, sweet potatoes, guinea grass and water spinaches

(Doan *et al.*, 2006). However, feeding is just one among several causes of low growth performances for rabbits.

According to Lebas *et al.* (1996), rabbits are sensitive to rude changes in environmental parameters, especially concerning temperature and hygrometry, which are changes that characterise humid zones in tropical regions. It is in such an environment that the integrated rabbit–fish–rice system will always be developed and the rabbits performed somewhat better than they do in some husbandries. Nonetheless, attention is to be paid at the earlier stage of rabbit development (newly born, and weaned) as they are more vulnerable. Finally, we would mention, however, that our rabbits were impure breed.

Fish growth and production performance

The growth parameters of Nile tilapia (final mean weight, SGR and DWG) were significantly higher in the treatment stocked with few fish (PT1: 1 fish.m⁻²) than in that stocked with more fish (PT2: 3 fish.m⁻²) but still under the same source of fertilisation. These parameters were highly density dependent while they correlated negatively with the stocking rate ($r = -0.988, -0.988$ and $-0.991, P > 0.05$) for final mean weight, daily weight gain and specific growth rate, respectively). Studies on fish farming in ponds with the fertilisation as the only source of nutrient input remain scarce in the literature, which is why the discussion here will confront current results to various farming styles of Nile tilapia.

Similar observations have been reported by various researchers, pointing to possible deterioration of water quality as caused by high stocking density (Yi *et al.*, 1996; Pankhurst *et al.*, 1997). These reasons include low DO at dawn, prolonged duration of low DO when compared with ponds with low stocking rates, as well as a high level of ammonia.

In this study, rabbit droppings allowed for fish a daily weight gain that fits into the range of weight gain reported by many authors for Nile tilapia when fed various pellets for example 0.30 – 0.47 g.day⁻¹ fish (Yi *et al.*, 1996), and 0.23–0.46 g.day⁻¹ in fertilised ponds by treated sewage-duckweed or fed commercial pellet (El-Shafai *et al.*, 2007b) or when reared in rice–fish culture in the same field (0.31–0.54 g.day⁻¹) (Chapman and Fernando, 1994; Vromant *et al.*,

2002a). This growth was, however, moderately lower than the weight gain (0.81–1.10 g.day⁻¹) reported for Nile tilapia when fed with feed that incorporates azolla (Abou *et al.*, 2007).

Numerous other authors observed a weak specific growth rate (SGR) and low daily weight gain (DWG) in high fish density ponds resembling our results. They argued that the low growth was either due to a general behaviour or physiological response to fish density itself (Diana *et al.*, 2004) or to a reduced availability of natural food in the ponds. In addition to this, those of our ponds with high densities demonstrated the lowest level of dissolved oxygen (DO), the highest level of ammonia, and reduced water transparency due mainly to the observed muddy state of the water.

Although no significant differences were noticed among treatments for the primary productivity and most of the water quality parameters, the changes observed on DO, ammonia and water transparency might have caused a stressful environment for the fish, thereby reducing the growth performance (Chapters 3 & 5). Also, a high concentration of food together with competitive interactions both for food and space in high fingerlings stocked ponds often weaken fish growth through stress to fish (Rahman *et al.*, 2005).

The present style of integration resulted in similar fish survival rates to that (87.7–88.7% for a stocking rate of 3 fish.m⁻²) obtained by Diana *et al.* (2004) for Nile tilapia stocked at 3, 6, and 9 fish.m⁻² and fed fish feed supplemented by nutrients from pond fertilisation that used urea and triple superphosphates. However, the fish survival rates in this study were better than those reported for Nile tilapia cultured in rice fields and their trenches, where the tilapia had weak survival rates of 61.5% (Vromant *et al.*, 2002a) and 69% (Frei *et al.*, 2007), thus supporting the argument that the rearing of fish in ponds, and the use of pond effluent to irrigate rice fields could prove to be a better method of rice–fish integration than is rearing fish in rice fields.

Contrary to growth parameters, fish net yield and annual production were in our study directly correlated to fish density ($R^2 = 0.9471$, $P < 0.001$ for yield). Highly stocked ponds (3 fish.m⁻²) resulted in a significantly higher yield ($P < 0.001$) than those stocked at 1 fish.m⁻². This finding was in accordance with the findings of Yi *et al.*, (1996) and El-Shafai *et al.*, (2007a) regarding

Nile tilapia in fertilised ponds supplemented with feed for which the fish yield was highest in high density ponds.

However, our fish yields were higher than those derived from tilapia fertilised by duck manure plus rice bran ($676 \text{ kg}\cdot\text{ha}^{-1}\cdot\text{crop}^{-1}$), chicken manure ($1539.2 \text{ kg}\cdot\text{ha}^{-1}$), and pig manure ($1414.4\text{--}1926.8 \text{ kg}\cdot\text{ha}^{-1}$) during 104 days (Hopkins and Cruz, 1982). The yield from the highest fish density pond ($1939 \text{ kg}\cdot\text{ha}^{-1}$) was also close to that ($2082 \text{ kg}\cdot\text{ha}^{-1}$) obtained when the fish were fed an azolla diet (28% crude protein) and were stocked at $3 \text{ fish}\cdot\text{m}^{-2}$ (Abou *et al.*, 2007). The yield from the highest density pond was also close to $2479.5 \text{ kg}\cdot\text{ha}^{-1}$ obtained for tilapia fed commercial pellet and put in freshwater (El-Shafai *et al.*, 2007b).

The results suggested that rabbit droppings are relatively better than other domestic manure in creating a favourable environment for tilapia growth even without supplemental feed. The water quality that is always favourable for fish is at most due to the constant refilling of the pond to compensate for reused pond water in rice irrigation. Furthermore, when compared with previous results from other experiments on tilapia farming (Teichert-Coddington, 1996; Long and Yi, 2004; Liti *et al.*, 2005), it appears that rabbit wastes are likely to better promote high fish density. This statement prompts further studies on fish density optimisation, performance and profitability when supplementing rabbit droppings fertilisers with fish feed, and effect of this combination fertilisers–feed on the production of secondary consumers (catfish) in a pond ecosystem while irrigating crops with effluents.

Rice production under organic versus inorganic fertiliser inputs

Most reports on rice–fish culture in literature suggest increasing rice yields in integrated systems as compared with rice monoculture. Rice yields are typically ranged from 2 to $5 \text{ t}\cdot\text{ha}^{-1}\cdot\text{crop}^{-1}$ (Frei and Becker, 2005c) in an integrated system, which implies a higher water requirement than any other annual crop in the world. We investigated a different integrated design that allows irrigating the rice field with water that was fertilised by having fish live in it so that the field benefits from the nutrients and the growing rice is thus fertilised.

Normal rice cultivation usually uses inorganic and organic fertilisers, which is a worldwide farming practice that produces high crop yields (De Datta, 1989, in [Yi et al., 2006](#)). The mean rice yields were not significantly different ($P>0.05$) during this experiment. Yields were slightly high ($5.87 \text{ t.ha}^{-1}.\text{crop}^{-1}$) in fields irrigated by effluent from the highly stocked fishpond (RT3), intermediate (5.79 t.ha^{-1}) in inorganically fertilised fields (RT1), and low (5.44 t.ha^{-1}) in fields fertilised by effluent from the lowest stocked fishponds (RT2). These results suggest the ability of rabbit droppings to completely replace inorganic fertilisers, that is the NPK and urea supplied during our experiment.

In fact, the analysis of nutrient flow throughout this rabbit–fish–rice system showed that effluent from ponds fertilised by rabbit droppings fertilised rice field at a rate of 3.98 kg N and $1.94 \text{ kg P.ha}^{-1}.\text{day}^{-1}$ ([Chapter 6](#)), which is equivalent to an application of urea and TSP at a rate of 4 kg N and 1.0 kg P ([Yi et al., 2002](#)). The obtained rice yields were quite similar to the highest yields ($3.5\text{--}6.0 \text{ t.ha}^{-1}.\text{crop}^{-1}$) for the *Yuni yin4* variety by local farmers operating under ISAR/rice programme supervision. However, the yields were higher than those ($2.86\text{--}3.08 \text{ t.ha}^{-1}$) from the *OM1490*; a high yielding variety used in Thailand, cultivated in rice monoculture fertilised with inorganic fertilisers compared to fertilisation by catfish pond effluent ([Yi et al., 2006](#)).

Reported yields from rice–fish systems in a single space in India and Bangladesh ([Mohanty et al., 2004](#); [Wahab et al., 2008](#)) seem to be always lower than those obtained in this study, despite the advantages of the addition of fish into the rice field. These advantages include: controlling weeds and pests, re-oxygenating the water, and facilitating nutrient assimilation by rice plant roots. Our paddy yields were however very close to the yields (4.4 t.ha^{-1}) obtained in the Sawah culture system applied in Ghana/west Africa ([Ofori et al., 2005](#)).

Rice straw biomass produced during this study doubled the rice paddy yield but it was estimated on a fresh weight basis. Even though no statistical differences existed among treatments ($P>0.05$) for rice straw yield, the straw yield was higher ($\pm 1 \text{ t.ha}^{-1}$ more) in RT1 than in the two other treatments receiving pond effluents. Treatment RT3 with effluent from the highest stocked pond (3 fish.m^{-2}) had the lowest straw yield.

This observation is in agreement with [Yi et al. \(2006\)](#) who reported lowest straw weight in fields fertilised by wastewater from catfish ponds and the highest in fields receiving NPK. As stipulated in the literature, the response of rice largely depends upon the variety used, the season, and the inputs supplied. We found that the number of panicles per m² was substantially bigger in inorganically fertilised fields as a result of the positive influence of urea on tillering and panicle initiation ([Vromant et al., 2002a](#); [Frei and Becker, 2005c](#); [Frei et al., 2007](#)), hence the highest straw weight in RT1.

Economic analysis of the IRFR system

The fixed and variable costs for this study were obviously higher in the integrated rabbit–fish–rice system than in the rice alone treatment as they involved rabbit hutch, fishpond and land rental costs, as well as labour, young rabbit, and fingerling expenses. The cost-benefit analysis thus based on the detailed costs of each treatment showed that the highest total cost was located in the treatments with integration, but also that the gross return in these treatments compensated the expenses. All treatments were significantly different ($P < 0.001$).

Furthermore, total investment costs and financial returns were density dependent in this integrated system mainly due to the high fish biomasses produced in ponds with high stocking rates. This is in accordance with [Lala I.P. Ray \(2010\)](#), who reported an increase of net benefit and reduced profitability value with increasing stocking density in integrated aquaculture within irrigation options.

From the present analysis, the integrated rabbit–fish–rice system overall generated a higher net return than that of rice monoculture. The net return increased in IRFR-1f and IRFR-3f by 343.9% and 596.9% respectively over that in rice monoculture (RA). The IRFR-3f also increased the net revenue over the IRFR-1f's one by 57.0% and the revenue above variable costs by 37.5%. The increase revenue over rice monoculture is higher than that reported in concurrent rice-fish. [Ofori et al. \(2005\)](#) found the percentage increase ranged from 5 to 11% while other researchers suggested that the addition of fish in rice has no effect on rice yield ([Rothuis et al., 1998](#); [Vromant et al., 2002a](#)). [Yaro et al. \(2005\)](#) found a weak effect and reported 4.6% increase of rice yield in rice-fish culture over rice monoculture.

The increase in net return in this study as the density increased was accompanied by a decreasing profitability due to the increase in investment costs. The farmer can therefore go for the integration by investing more in order to make higher net returns. The net return increase was mainly a result of integrating fish with the rice.

7.5 Conclusion

Various resources including animal manure, human wastes, compost, and green grass, have been used as organic fertilisers in fish production throughout the world. Integrated rabbit–fish–rice system has the potential to increase net returns and that these returns are fish density dependent.

Furthermore, the study demonstrated: (1) the capacity of growing rabbits to adapt in a humid area as they increased their weight by 127% in 101 days, reaching a production of 1.4 kg.ha⁻¹ of pond; (2) the yield performance of fish Nile tilapia up to 1939 kg.ha⁻¹ equivalent of about 3.3 t.ha⁻¹.yr⁻¹ in fertilised ponds without supplemental feed; and (3) rice paddy and straw yield performances of up to 5.87±0.2 t.ha⁻¹.crop⁻¹ of rice paddy and 9.97±0.1 t.ha⁻¹.crop⁻¹ of rice straw (fresh weight) without any other input.

In terms of economics, the net return of the whole system was further enhanced by 596.9% in the rabbit–fish–rice system with 3 fish.m⁻² (IRFR-3f) over that of the rice culture, and by about 57% over the net return in the IRFR-1f. These performances substantiate the sustainability of the integrated rabbit–fish–rice system, especially for low to medium-resource farmers. It can therefore be concluded that the Integrated Rabbit–Fish–Rice system (IRFR) works well and as such promises economically sound and ecologically friendly management.

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8. CHAPTER EIGHT: General Discussion, Conclusions and Recommendations

The following paper is based on the chapter 8:

RukeraTabaro, S., Mutanga, O., and Micha, J.-C. 2011, Optimisation of an Integrated Rabbit–Fish–Rice System for Sustainable Production in Rwanda, *Rwanda Journal*, Vol.24 (E-2011)pp 28–38.

Abstract

An innovative integrated agriculture-aquaculture (IAA) system, suitable for resource-poor rural farmers, was proposed and tried at the Rwasave Fish Farming and Research Station, National University of Rwanda (SPIR-NUR). The system components were rabbits, fish (Nile tilapia), and rice: the integrated rabbit–fish–rice (IRFR) system. The research aimed at investigating an integrated system to optimise its production hence contribute to eradicating extreme poverty, enhancing food security, as well as abating environmental degradation. These are some of the Rwandan government’s main goals regarding agriculture and environment in its 2020 vision programme. After a series of experiments consisting of the rearing of rabbits at various densities over fishponds and the re-use of pond effluent to fertilise rice fields, the study revealed the following: rabbits adapted well to the conditions of wetlands; the density of 800 to 1200 rabbits per ha of ponds was the optimum for sustaining the integrated system; rabbit droppings contributed 27% N and 79% P of the total nutrient N and P fertilising fishpond input (the major source being on-farm resources); the integrated system showed higher economic returns of up to 597% net return (NR) over rice monoculture NR and up to 57% NR of the rice-fish system NR. It was concluded that the IRFR system works well and can be promoted for optimum resource use, better income generation, and environmental friendly production.

8.1 Introduction

Poverty and food insecurity continue to characterise developing countries and are associated with population escalation and the scarcity of available arable land. The insufficiency of land and the small size of farm per household, in addition to a notable lack of agrarian technology skills, make food shortages, famine, and environmental degradation major concerns in these countries. Small-scale farmers and their dependent households who try to wrest a living from small-scale farms are constantly exposed to food insecurity (Edwards *et al.*, 2000; Murshed-E-Jahan and Pemsil, 2011). The need for training in the appropriate technology of integrated production as well as ecological principles that include renewable resources are considered as key to the sustainable development of rural farmers (d'Oultremont, 2000; Karim, 2006).

Integrated Agriculture-Aquaculture (IAA) systems traditionally rely heavily on the use of agricultural by-products for fish production, including plant scraps, animal manure, and other wastes (for example, slaughter wastes). However, these by-products result in low fish yields, prompting the use of supplemental fish feeds to boost productivity (Yi and Lin, 2000a; Diana *et al.*, 2004). These feeds are very expensive and unaffordable to subsistence rural farmers; this is reported to be the main reason for farmers not engaging in aquaculture (Omondi *et al.*, 2001 in Karim, 2006). In addition, even though intended to benefit poor farmers, stand-alone fish farms and simple two-component systems such as chicken-fish, pig-fish have always failed after support is withdrawn (Prein, 2002).

The above challenges apply to Rwanda, a developing country and one of the most densely populated countries in eastern Africa, with 384 individuals per km² and a 2.82% annual population escalation rate (NISR, 2010). However, Rwanda has assets likely to favour integrated aquaculture enterprises: abundant rainfall, moderate temperatures, cheap and abundant labour, and widespread marshlands (10.5% of the country).

The present thesis reports on research experiments conducted at the Rwasave Fish Farming Research Station (2°40'S and 29°45'E), National University of Rwanda, Butare, Rwanda, over the period 2008 – 2010. The overall goal of this PhD research, carried out under a sandwich programme in two universities: The University of KwaZulu-Natal / School of Environmental

Sciences, and the National University of Rwanda between August 2006 and June 2011, was to contribute to the improvement of food security, poverty reduction, and thus the overall livelihoods of resource-poor, small-scale farmers of Rwanda. It aimed at achieving the following specific objectives through an integrated system composed of rabbits (*Oryctolagus cuniculus* Linnaeus), fish (Nile tilapia *Oreochromis niloticus* Linnaeus), and rice (*Oryza sativa* Linnaeus) farmed on a reduced area of land and likely to increase diversified production:

- a) Determine the overall effects of rabbit droppings on pond water physico-chemistry and primary productivity for a better environment of Nile tilapia
- b) Identify all intervening resources, describe their flow within the system, and characterise the role of pond effluent in fertilising the rice field;
- c) Optimise the density of the rabbit component to be capable of maintaining the sustainable production of all other components of the integrated rabbit–fish–rice system;
- d) Assess the flow of nitrogen and phosphorus nutrients in the integrated rabbit–fish–rice system and consequent production of each component of the system;
- e) Evaluate the production performances and profitability of the integrated rabbit–fish–rice system through a cost-benefit study of each component versus that of the whole system.

The integrated rabbit–fish–rice (IRFR) system was designed. The sub-units of the system were enterprises that depended totally on the recycling of sub-products of components to enhance the production of others.

8.2 Adaptation of rabbit in wetland conditions and profit from its droppings

Rabbits, on exceptionally wide and varied diets, show enormous adaptability to conditions ranging from the tropical to arctic regions (Sandford, 1992, in Marai and Rashwan, 2004). Optimal conditions for rabbits are between 13–20°C (average 15°C) air temperature; 55–65% (average 60%) relative humidity; at least 0.17 m³.min⁻¹ air flow ventilation capacity; and wind velocity of 5–18 km.h⁻¹. Rabbits, however, do react to changing climatic conditions. At Rwasave, as in most of the Rwandan marshes, climatic conditions change continuously. The minimum temperature drops to between 10–15°C during cold nights and the highest temperatures reach 30°C in the afternoons. The humidity varies between 59% and 83% with an annual average precipitation of 1200 mm. The response of rabbits to such conditions was thus of concern at the outset of the experiment.

The fluctuation of temperature and humidity in marshes such as Rwasave was a potentially serious constraint on the production and reproduction of rabbits due to the heat stress that occurs in a hot environment (Fernandez *et al.*, 1994, in Marai and Rashwan, 2004). Above fishponds, heat stress occurs at even lower temperatures than the minimum ordinarily tolerated by rabbits (13°C), due to the high humidity that increases the feeling of warmth.

Nonetheless, all three experiments of this study showed good ranges for rabbit survival rates. We observed that a housing made from wooden planks, and covered with thatch underneath sheet-metal, alleviated heat stress, thus resulting in rabbit survival rates from 95.8% to 85.4%, daily weight gain from 11.4 to 8.0 g.day⁻¹, and from 500 to 2000g for 2 rabbits .m⁻² hutch and from 805 to 1363 g rabbit mean weight for 4 rabbits.m⁻² surface hutch.

A further strategy was not to involve rabbit kits in the investigation as they are known to be vulnerable to stress (at birth they are hairless, with sealed ears and eyelids, and only able to crawl). Rabbit kits were specially raised in indoor hutches and moved to pond hutches when weanlings.

This study showed the potential adaptability of rabbits to a humid area if care is exercised, thus farmers should be advised of this and encouraged to provide more care during harmful seasons (especially the hot one).

8.3 Rabbit above fishponds: effects on water quality, plankton and fish production

Organic fertilisers, such as livestock manure (rabbit droppings in the current study), are the principal input of IAA systems to stimulate the aquatic food web and improve fish production by stimulating primary and secondary productivity (Hepher and Pruginin, 1981; Delincé, 1992; in Brein *et al.*, 1996). The specific feature of this experimental IAA system was the rearing of rabbit over fishponds, allowing the water to benefit from the entirety of produced manure that is both solid dung, and urine which contributed on its own 20.0% N and 64.0% P of the nitrogen and phosphorus of the total input to the fishpond.

8.3.1 Rabbit droppings as a water fertiliser

The design for this research allowed rabbit droppings to be discharged into the water constantly, decomposed by bacteria, and gradually releasing nutrients, especially nitrogen, in the form of ammonia, nitrites, and nitrates, and phosphorus; all nutrients encouraging phytoplankton growth. This released nitrogen in the water favoured microbial activities that resulted in considerable changes in the whole physico-chemical composition of the fishpond water.

Temperature, water transparency, dissolved oxygen (DO), and pH concentrations obtained for these parameters, however, remained in the range required for sustainable fish production (Table 3.2). The temperature of the water fluctuated between 20.0 and 25.3°C, DO from 1.67 mg.l⁻¹ for morning measurements (indicating night microbial activities that consume oxygen) to 10 mg.l⁻¹ in the afternoon (owing to algal photosynthesis). The morning DO levels were always lower than the minimum acceptable for fish (3 mg.l⁻¹) (Mmochi *et al.*, 2002) but fortunately, because of the tropical location, the length of daylight allowed early photosynthesis that provided DO (Boyd and

Queiroz, 2001; Mmochi *et al.*, 2002; Tepe and Boyd, 2002). The changes induced in the physico-chemistry of the water included diurnal changes of pH and DO, as well as the increase over time of water conductivity and primary productivity. The fluctuation of pH and DO noted during the study between morning and afternoon values could probably be explained by phytoplankton consumption of carbon dioxide for the photosynthesis process. Low morning pH could have been caused by the respiration of all living organisms which discharged carbon dioxide in the ponds. Burford *et al.* (2003) argued that pH averaging 8 accounted for high levels of inorganic nutrients in shrimp ponds, whereas daily pH fluctuations between 6.5 and 9.5 are not uncommon in ponds rich in phytoplankton (Engle *et al.*, 1993).

Although none of the physico-chemical parameter reached harmful values for the relatively low rabbit stocking rates experimented with in Chapter 3 (100, 200, and 400 rabbits.ha⁻¹ of pond), the current study found that the water quality parameters, especially inorganic nitrogen, were rabbit density dependent. For example, in Chapter 5, harmful ammonia of 1.04 and 1.12 mg.l⁻¹ was found in treatments using 800 and 1600 rabbits.ha⁻¹ respectively. nitrites and ammonia concentrations are most likely dependent on fertilisers load (Franco, 1991; Diana *et al.*, 2004) and their levels in water especially in tropical conditions, are potentially subject to fluctuations during the day as the equilibrium concentration within ionised and non-ionised ammonia is a function of temperature and pH (Van Rijn and Rivera, 1997; Boyd and Tucker, 1998; Knud-Hansen *et al.*, 1998)

The optimal rabbit density for a sustainable IRFR system could be in the range of 800–1200 rabbits.ha⁻¹, beyond which the net fish yield declined, owing mainly to the degradation of water quality.

Finally, the most pronounced gain from rabbit droppings is that phytoplankton biomass produced under such fertilisation had greater value than that observed by other researchers in artificial substrates in ponds (Azim *et al.*, 2002), and there is a positive significant correlation between Chl *a* and rabbit droppings ($r = 0.7247$; $P = 0.006$). This correlation signals the importance of rabbit droppings in boosting Nile tilapia growth and production through the increase in phytoplankton biomass (Chl *a*).

8.3.2 Rabbit droppings improve Nile tilapia growth and production

In the research on which this thesis reports, better net fish yields (NFY) were obtained in ponds receiving 22 kgDM.ha⁻¹.day⁻¹ rabbit dung when compared to those receiving 6, 16, 26, and 35.5 kgDM.ha⁻¹.day⁻¹ (Table 8.1) corresponding to various densities of rabbits (Chapter 5 and Chapter 6).

Generally a major concern in integrated aquaculture is that, over time, organic matter, nutrients and soil accumulate in the pond water and on the bottom where decomposition by bacteria transform un-toxic nutrients into toxic forms of nutrients. This decrease in water quality stresses fish slowing their growth, and can sometimes lead to fish mortality (Boyd and Tucker, 1998; Knud-Hansen *et al.*, 1998). But the design of the current study is likely to favour fish production as it allows for gradual fertilisation; this prevents quick degradation of water quality as reported by Breine *et al.* (1996). This study's pattern also includes prompt application of good managerial techniques such as regular refilling of the pond; renewing of water; effluent reuse and replacement. All these practices allow for availing nutrients that boost plankton production and, consequently, Nile tilapia growth and production. Nonetheless, there remains an optimal level beyond which fish production declines.

Also, studies on the effect of fertilisation frequency (Garg and Bhatnagar, 2000), and on the optimisation of fertilisation rates (Azim *et al.*, 2001), mention that fish biomass and fish specific growth rate (SGR) are correlated with a high release of nutrients in water. In addition, this study showed that a strong relationship through multiple linear regression analysis ($R^2 = 0.9000$ and equation $y = 0.5 + 1.4x - 0.1x^2$), existed between the amount of rabbit droppings (created by rabbit density) and the fish yield although it is important to note that beyond 1200 rabbits.ha⁻¹ of pond, fish yield and survival drop substantially even though the plankton biomass increased.

Thus it can be argued that fish production that depends on the availability of plankton on which tilapia feed almost exclusively in fertilised waters, is improved by rabbit droppings until the point when fertilisers and the plankton biomass become too great.

Table 8.1: Variation of dissolved oxygen, ammonia, plankton biomass, fish yield and fish survival according to rabbit density and related dung excreted into fishpond

Rabbits density (rabbits.ha ⁻¹)	Rabbit solid dung (kgDM.ha ⁻¹)	Dissolved oxygen mg.l ⁻¹	Ammonia mg.l ⁻¹	Plankton biomass µgChla.l ⁻¹	Net fish yield kg.ha-1.y ⁻¹	Fish survival %
200	6	4.6 ± 1.4 ^a	0.5 ± 0.4 ^a	44.8 ± 20.7 ^a	11.3 ± 4.0 ^a	85.2 ± 11.3 ^a
400	16	4.9 ± 1.3 ^a	0.7 ± 0.3 ^a	45.8 ± 22.3 ^a	18.4 ± 3.5 ^b	91.4 ± 1.8 ^a
800	26	1.7 ± 1.5 ^b	1.0 ± 0.4 ^b	57.9 ± 52.6 ^a	23.8 ± 3.2 ^b	84.2 ± 9.6 ^a
1200	22	1.7 ± 1.2 ^b	0.5 ± 0.4 ^a	71.5 ± 42.7 ^{ab}	32.6 ± 2.6 ^c	89.2 ± 4.4 ^a
1600	35.5	1.3 ± 1.8 ^a	1.1 ± 0.6 ^b	93.0 ± 77.8 ^b	22.1 ± 3.5 ^b	72.5 ± 3.5 ^b
<i>LSD</i> _{0.05}		1.08 (*)	0.48 (*)	31.17 (**)	6.85 (**)	13.6 (NS)

Values are mean ±SD from three replicates and eight sampling dates. Figures with same superscript letters are not significantly different ($P < 0.05$). *LSD* (5% level): Least Significant Difference obtained by Analysis of variance

8.4 Flow of bio-resources and nutrients within the integrated rabbit–fish–rice system

As for any sustainable IAA system for resource-poor farmers, the major sources of nutrients in this integrated rabbit–fish–rice system were “on-farm resources”. The non-utilisation of manufactured concentrates and the use of small animals (less demanding in their alimentation), and the complexity of the system by the reuse of effluent in an additional production enterprise (the rice fields), make it an exceptional type of IAA system with a flow of bio-resource inputs and nutrients that entail fewer negative concerns.

8.4.1 Bio-resource flow and source of nutrient in the IRFR system

As with most IAA systems, the entry point of this IRFR system was the livestock participating in the system, that is, the rabbits that were fed grass from the surrounds of fishponds and dropped their dung and urine into the fish pond water. These on-farm resources (grass and rabbit droppings), together with pond effluent used to fertilise the rice fields, accounted for 89.0% of the total N and 92.3% of the total P input. Their contribution was greater than that observed in the Mekong valley (Vietnam) where on-farm resources accounted for only 32% of total N and 65% of all the P and carbon as many of those farmers supplemented fish feeding with pellets and orchid farms with inorganic fertilisers (Nhan *et al.*, 2008). Although the nutrient contribution by on-farm resources in the IRFR system do not exceed the nutrients (95.0% TN and 97% TP) reported by Yi *et al.* (2006) when discussing a system that used the effluent of catfish ponds for irrigating rice, the major source of nutrients in the latter were fish concentrates (off-farm resources) fed to the catfish.

In the IRFR system at Rwasave, fish production depended on rabbit density, that is, the number of rabbit over a surface of ponds corresponding to rabbit droppings load. This is in accord with Hopkins and Cruz (1982), who optimised the use of pigs, chickens, and ducks in integration with tilapia fish farming, and various other integration with Nile tilapia farming (Diana *et al.*, 2004; Nhan *et al.*, 2008).

As a further result, the present research revealed (Chapter 6) that fish stocking density did not exert a significant impact on the physico-chemical quality of fishpond water. Two densities (that is, 1 and 3 male juvenile tilapia per m²), were applied, and the ponds of both treatments were fertilised by the same optimal rabbit density with no significant differences regarding physico-chemical and nutrients quality of fishpond water. The constant renewal of pond water after effluent reuse in irrigating the rice field might explain this absence of differences.

The only major off-farm resource in IRFR is the influent fishpond water which provided up to 73% N and 21.0% P as a source of the nitrogen and phosphorus input to the pond. The high contribution exhibited here is a matter of magnitude as water used for rice irrigation had to be replaced every day. The influent might have been principally constituted of dissolved organic

nitrogen (DON) from the rice and vegetable fields upstream of the fish-farming station. The DON is decomposed only slowly by bacteria and therefore accumulates over the rearing time (Burford *et al.*, 2003), thus remaining the major form of nitrogen in fishponds (Jackson *et al.*, 2003; Nhan *et al.*, 2008). Hence the nutrients available after rabbit dropping decomposition by bacteria may have been mostly utilised by phytoplankton development serving to feed the tilapia.

8.4.2 Fishpond water fertilisation and nutrients distribution

Soon after the first month of fishpond fertilisation by rabbit dropping nutrients, N and P fluctuated noticeably. The N decrease was probably due to the removal of water for rice field irrigation. Nutrient flow analysis in the IRFR system showed that 27% N and 79% P of the total N and P input in the fish ponds were accounted for by rabbit droppings, and these droppings fertilised fishponds at the rate of 3.98 kg N and 1.94 kg P.ha⁻¹.day⁻¹. This rate is higher than that (1.75 kg N and 0.39 kg P.ha⁻¹.day⁻¹) reported in an integrated Nile tilapia cage-cum-pond system by Yi *et al.* (2003c) where tilapia were fed with pellets. Research by Prein (2002) and Nhan *et al.* (2008) reported that an increase in pond production depends on on-farm resources, mainly livestock wastes, plant remnants, and by-products.

The fertilisation rate provided by rabbit droppings and other on-farm sources of nutrients was comparable to the application of inorganic fertilisers TSP and urea at the rate of 4 kg N and 1 kg P.ha⁻¹.day⁻¹ used by Yi *et al.* (2002) in an integrated Lotus–Tilapia experiment and which resulted in Nile tilapia net yield (3.3 kg.ha⁻¹.yr⁻¹) comparable to that reported in Chapters 6 and 7 of this thesis: 3.5 kg.ha⁻¹.yr⁻¹ for a density of 3 fish.m⁻², reared without any supplemental feed. The fertilising input increased the N concentration by about 93.3% (0.2–3.2 mg.l⁻¹ TN) and 98.5% (0.01–0.66 mg.l⁻¹ TP) in the fishpond.

The overall on-farm resources of the reported research, including rabbit droppings (dung and urine) and the pond effluent water for rice fields, accounted for 89.0% of the total N and 92.3% of the total P input in rice fields. This contribution fertilised rice fields at a higher rate (that is 118.5 kg N and 27.2 kg P.ha⁻¹.day⁻¹) than that of inorganic fertiliser (NPK and urea) application.

Additional nutrient contributions to the IRFR system could have been the canal water, the fish waste, the plankton die-off, other external unaccounted sources such as levee and watershed erosion, small leaves from the rabbit hutches, leaves blown into the pond by the wind, as mentioned by [Yuvanatemiya and Boyd \(2006\)](#), and fish excretion. For example, [Piedrahita \(2003\)](#) observed that tilapia excreted up to 59 - 72% of the N and 60 - 62% of the P constituent in the feed. In addition to nutrient use in plankton growth and other living organisms in fishponds, the destiny of the nutrients is dominated by the accumulation in pond sediment (*not quantified here*) and fishpond water that was used to irrigate the rice fields as largely detailed in the sections below.

8.4.3 Recovery of nitrogen and phosphorus by harvested products

The nutrient (N and P) recovery achieved by the IRFR system is compared to the recovery from various sources of nutrients, including fish feeds, in Table 6.4 *page 133*. This comparison shows that when nutrients from feeds are used directly by fish, the recovery rate is higher than that of nutrients from fertilisers. [Tacon *et al.* \(1995\)](#), cited by [El-Shafai *et al.*, \(2007a\)](#) found that supplementary feed in semi-intensive farms improved nitrogen recovery in fish from 5% to 25%.

The Nile tilapia in the current research recovered 37.6% N and 34.3% P of the total N and total P in the rabbit dropping input; this was 10.2% N and 27.13% P of the total inputs, including the canal water that refilled ponds. The N and P recovery in the IRFR system was higher than the range of 12.75 – 22% N and 14.3 – 27% P shown by other IAA systems that use fertilisation as a source of nutrients. This suggests that rabbit droppings would be utilised in fishponds more efficiently than many other inputs, ensuring a better environment for Nile tilapia growth.

Nonetheless, the research showed a very low nutrient recovery by rice grain and straw from the accumulated nutrients in the fishpond water effluent to irrigating the rice fields (Chapter 6). This was probably due to the huge amount of effluent supplied. The recovery in fields irrigated by effluent was lower than in fields receiving inorganic fertilisers, suggesting that a large quantity of nutrients supplied in effluent is deposited in the soil, lost in seepage, or promotes weed growth during the farming period. In fact, we found that the seepage water alone accounted for between

80 and 88% of TN and TP of the effluent that entered the rice field, about 29 to 40% of the soluble phosphates, but, more encouragingly, only up to 6.0% of the nitrates.

8.4.4 Nutrients in pond sediment, rice field soil and seepage water

The determination of the pond water nutrient budget is prone to errors, particularly when it involves precise quantification of the amount of sediment, seepage, and nutrient consumption by plants. Thus the distribution of nutrients in the sediment and rice field soil is based on differences in nutrient concentrations. In this research, the IRFR system allowed an increase of total nitrogen and ammonia- nitrogen, as well as total phosphorus and phosphates, from the start of the study up to midterm (that is, 90 days) followed by a decrease to the end of the experiment - except for ammonia nitrogen.

This pattern is similar to observations by many authors in integrated aquaculture. Phosphorus is strongly adsorbed by pond soil directly from pond water (Knud-Hansen *et al.*, 1998; Boyd, 2001b), and Yuvanatemiya and Boyd (2006) found that organic matter, nitrogen, phosphorus, and total phosphorus in pond bottom soil accumulate strongly in the upper 10-20 cm of sediment as a result of the fertilisation process through microbial activity.

High concentrations of ammonia, total nitrogen, and total phosphorus nutrients, due to fertiliser application and irrigation by effluent, were found in the rice fields only at the beginning, and they decreased towards the end due, probably, to the nutrient uptake by rice in the growing phase. Vromant and Chau (2005) indicated an increase of nutrients in soil during the first 15 days after transplanting (DAT) thus reporting a high prevalence of strong nitrification processes in the upper layer of the soil, transforming ammonia into nitrates better used by the rice.

8.5 Performance and profitability of Nile tilapia and Rice production

Integrated farming systems diversify production, benefiting from synergisms between the components of the system: the by-products of one become the input of the other. For that the integrated agriculture-aquaculture (IAA) is considered a sustainable agriculture model for rural poor farmers (Prein, 2002; Nhan *et al.*, 2008) and an easy mean of improving the livelihoods of the poor through food supply, employment and income (Karim, 2006; Murshed-E-Jahan and Pemsil, 2011). Nonetheless the IAA is still contrasted by a concern of low monetary returns (Belton *et al.*, 2009; Costa-Pierce *et al.*, 2010).

The current research proposed an innovative technological development of three levels of production and Chapter 7 of this thesis focused on performances at each level of production. This complex integration, we believe, can contribute successfully to the needs of resource-poor farmers in the agrarian economy of developing countries, but it is necessary to assess the production performances and the system profitability in order to evaluate its sustainability for the poor and its relation to the environment.

8.5.1 Tilapia and rice performances in the IRFR system

When the integrated system used optimum rabbit and fish densities, fish growth was inversely dependent on the density. Fish growth parameters remained negatively correlated with the fish stocking density ($r = -0.988$, -0.988 and -0.991 for final mean weight, DWG, and SGR respectively). In contrast, multiple regression showed a strong relationship between the production parameters (NFY, yield, and biomass) and the fish density ($R^2 = 0.9471$, $P < 0.001$ for yield).

Similar trends for growth have been reported previously, indicating a possible deterioration of water quality caused by a high stocking density (Yi *et al.*, 1996; Pankhurst *et al.*, 1997) which implies a large quantity of feed thus a large quantity of waste. However, the fish daily weight gains (DWG) in the IRFR always ranged in the common Nile tilapia DWG reported when fish were fed concentrated feeds: $0.3 - 0.5 \text{ g.day}^{-1}$ (Yi *et al.*, 1996); $0.2 - 0.5 \text{ g.day}^{-1}$ in fertilised ponds by treated sewage-duckweed; fed commercial pellet (El-Shafai *et al.*, 2007b) or when

reared in rice–fish culture in the same field (0.3–0.5 g.day⁻¹) (Chapman and Fernando, 1994; Vromant *et al.*, 2002a).

Results from the present research on fish production suggested that rabbit droppings could be a better fertiliser when compared with many other tilapia production systems where the fish are fed concentrates or fertilised by various types of manure (Hopkins and Cruz, 1982; Abou *et al.*, 2007). This finds support in Chapter 6 when comparing tilapia nutrient recovery in ponds receiving various types of fertilising sources. Rabbit droppings must be more easily decomposed by microbial activity in fishponds than many other inputs, therefore releasing nutrients that serve for phytoplankton development - primary natural food for Nile tilapia.

Higher rice yields but not significantly, characterised the IRFR system than the inorganically fertilised rice: average of 5.8 and 5.9 t.ha⁻¹ against 5.4 t.ha⁻¹ in rice alone). These yields however were higher than those (2.9–3.1 t.ha⁻¹) from the *OMI490* (a high yielding variety used in Thailand cultivated in rice monoculture fertilised with inorganic fertilisers compared to fertilisation by catfish pond effluent (Yi *et al.*, 2006). The IRFR yield however could be compared to the typical range (2–5 t.ha⁻¹.crop⁻¹ as reported by Frei and Becker (2005c) in an integrated system, which implies a higher water requirement than any other annual crop in the world.

We found that our research rice fields were fertilised at a higher rate (118.5 kg N and 27.2 kg P.ha⁻¹.day⁻¹) than that of inorganic fertilisers, and this resulted in the slightly higher rice yield in IRFR than that induced by NPK and urea. Nutrient-rich effluent from the tilapia ponds in the IRFR system were, as compared to catfish pond effluent (Yi *et al.*, 2006), capable of completely replace the inorganic fertilisers, that is, NPK and urea, supplied during our experiments in the rice fields. Reported yields from rice–fish systems in a single space in India and Bangladesh (Mohanty *et al.*, 2004; Wahab *et al.*, 2008) seem to be always lower than those obtained in this study.

8.5.2 Rabbit production performance

This research showed that weanling rabbits adapt to the humid environment as they managed to perform well and increase their mean weight by 46.85% (from 726.7 ± 10.3 to 1364.1 ± 38.3 g.rabbit⁻¹) during the 101 days they were fed grass only. The recorded growth rate (6.31 g to 15.96 g.day⁻¹) was low, but still close to the general growth rate range for rabbits (10 to 20 g.day⁻¹) found in tropical regions (Samkol and Lukefahr, 2008), and even higher than 2.27 or 5.72 g.day⁻¹ reported on rabbits fed with mulberry leaves or concentrates respectively (Bamikole et al., 2005).

The major reason for low performance would be the changes in environmental characteristics. According to Lebas *et al.* (1996), rabbits are sensitive to rude changes in environmental parameters, especially in temperature and hygrometry, which are changes that characterise humid zones in tropical regions.

8.5.3 Cost-benefit analysis of the present IRFR system

As with all IAA systems, the IRFR research system seemed to be characterised by higher total investment costs than it is normally in paired integrated enterprises, and this could obviously frighten a poor farmer from adopting it. This thesis shows that costs were significantly dependent on stocking density and that the gross return could easily compensate for the expenses and increases the net return. This is in accordance with Lala I.P. Ray (2010), who reported an increase of the net benefit and reduced profitability with increasing stocking density in integrated aquaculture within irrigation options.

The net return increased in IRFR-1fish.m⁻² and IRFR-3fish.m⁻² by 343.9% and 596.9% respectively over that in rice monoculture (RA). The net revenue also increased in IRFR-3fish.m⁻² by 57% over other IRFR-1f; this increased the net revenue by 37.5% over rice alone.

The revenue increase over rice monoculture returns are greater than those reported in concurrent rice-fish. A number of researchers suggest that the addition of fish in rice fields has no effect on rice yield (Rothius *et al.*, 1998; Vromant *et al.*, 2002a), while Ofori *et al.* (2005) report a percentage increase ranging from 5 to 11%, and Yaro *et al.* (2005) found a weak effect and reported 4.6% increase of rice yield in rice–fish culture over rice monoculture. Compared to these observations, the IRFR system appears more economically efficient than the rice–fish system.

8.6 Conclusions

The success of a fish farming enterprise lies in the comprehension and implementation of adequate techniques that enable the farmer to maintain successfully water quality, correct fertilisation and feeding, as well as handling stock on the farm while avoiding all forms of threat to the environment. Given that aquaculture ponds play an important role in the nutrients cycling through mixed farming systems, the best technique likely to increase production would be the integration of various agriculture enterprises with aquaculture ponds.

The present research aimed at investigating an innovative, integrated agriculture-aquaculture system, the integrated rabbit–fish–rice (IRFR) system, in order to optimise agricultural production in a sustainable and environmentally friendly way. As supported by a number of authors, the integration allowed for nutrients contained in agricultural by-products and livestock wastes to contribute to the production of aquatic food products and nutrient-rich water and sediment in ponds; the water and sediment in turn irrigated flooded crops and the sediment fertilised terrestrial cropping. In this way, expensive inorganic input was avoided.

From this research, we believe that the IRFR system has enormous potential for water fertilisation, plankton growth and production. Fishponds that receive rabbit droppings conserve a good quality of water and are less turbid than those fertilised by all other domestic animal manure, but the water quality (transparency, dissolved oxygen, inorganic nitrogen, and chlorophyll *a* for phytoplankton biomass) is dependent on rabbit density and rabbit dropping load.

The optimal density of rabbits has been determined at 800–1200 rabbits.ha⁻¹ of pond. The constant use of the pond effluents improves the water quality in ponds, thus providing an improved means of renewing pond water on the one hand and enhancing the production of the irrigated unit on the other.

In the IRFR system, the main source of nutrients were on-farm resources, constituted mainly of rabbit droppings accounting for up to 27% N and 79% P of the total N and P in total fishpond inputs. Rabbit droppings allowed for a fertilising rate of 3.98 kg N and 1.94 kg P.ha⁻¹.day⁻¹, capable of causing a net fish yield of 2.0 – 3.3 t.ha⁻¹.yr⁻¹ without any feed supplement.

The IRFR system implies the re-use of the nutrient-rich effluent, which allows for the recycling of N and P nutrients by providing the growing rice with required nutrients at a high rate (118.5 – 125.3 kg N and 22.9 – 21.2 kg P.ha⁻¹.day⁻¹). As such, the system improved rice production that was, 5.87 t.ha⁻¹.crop⁻¹ of rice paddy and 9.97 t.ha⁻¹.crop⁻¹ of rice straw (fresh weight) without any other input.

Finally, the IRFR system demonstrated its potential to increase economic returns always dependent on stocking density. The integrated system here generated up to 597% net return over that of rice inorganically fertilised and 57% over the low fish stocking density. However, while net return increased with increasing stocking density, the profitability (benefit-cost ratio) decreased, suggesting that a farmer should commit to full integration, as investing more provides a guarantee of higher net returns.

The growth, production, and economic performances, together with the potential to maintain good water quality for fish farming, substantiated the sustainability of the IRFR system, especially for low- to medium-resource farmers. It is concluded that the IRFR system is viable, works well, and, as such, promises economically sound and ecologically friendly management.

The IRFR system can therefore be promoted with the aim of reducing poverty and improving food security for poor farmers. Pond management practices could focus on the monitoring of various flows in order to intelligently increase resources for better production, and improve profitability for farmers while mitigating threats to the environment.

8.7 Mandate for the future

Overall, this research showed that this innovative IRFR system promises economically and sustainable development, therefore prompting the need for further research and extension planning:

- The functioning of the IRFR systems should be further studied from the socio- economic aspect, trying to address consumer and farmer perceptions on the adoption of the system and the implications on the livelihoods of farming households.
- Further research should establish the temperature-humidity index (THI) of the marsh and use all rabbit growth stages in integration with fish and crop production.
- Specific study should establish qualitative and quantitative databases for each component of the integration and their interrelations to describe a model. Research must be conducted on the chemical characterisation of nutrients in water, sediment and fish in order to determine a nutrient budget of the IRFR.
- A study to improve the efficiency of nutrient recovery as well as the impacts of the IRFR on terrestrial crops farmed on pond dykes can contribute to food security of poor farmers owning fishponds.
- The effect of the IRFR on fish polyculture for an efficient use of available resources in the environs of the integrated farming system needs to be investigated in a thorough study.

This research drew our attention to:

- The development of effective extension mechanisms based on the current findings to promote the use of integrated fish farming systems;
- The establishment of integrated fish culture farms in all irrigation reservoirs to diversify products and improve agriculture downstream the reservoirs.

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