Optimization of an Integrated Rabbit-Fish-Rice System for Sustainable Production in Rwanda

Rukera Tabaro S.*[1], O. Mutanga[1], and J.-C Micha[2]

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's components were rabbits, fish **(Nile tilapia),** *and rice: the integrated rabbit–fish–rice (IRFR) system. The research aimed at contributing to Rwanda government's goals of eradicating extreme poverty and hunger, enhancing food security as well as abating environmental degradation. After a series of experiments consisting of the rearing of rabbits at various densities over fish ponds and the re-use of pond effluent to fertilise rice fields, the study revealed the following: rabbit adapted well in the conditions of wetlands, the density of 800 to 1200 rabbits per ha of ponds was found to be the optimum for sustaining the integrated system, and rabbit droppings contributed 27% N and 79% P of the total nutrient nitrogen and phosphorus in fertilizing input in fishponds, the major source being on-farm resources. The integrated system showed higher economic returns than both rice monoculture and rice-fish system. It was concluded from this study that the IRFR system works well and can be promoted for optimum resources use, better income generation, and environmental friendly productions.*

Keywords: *Integrated rabbit-fish-rice system; optimum density; resources and nutrients flow, resources-poor rural farmers, performance and profitability*

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* Corresponding author, National University of Rwanda, Faculty of Agriculture / Department of Animal Production, P.O Box 117, Butare – Rwanda, Email: srukera@nur.ac.rw

[1] University of KwaZulu-Natal / Faculty of Sciences and Agriculture, School of Environmental Sciences / Centre for Environment, Agriculture & Development, Private Bag: X01 Scottsville, 3209 Pietermaritzburg (South Africa); Cell phone: +27(0)73 551 7039 / Fax: +27(0)33 260 6118, Email: simon.rt@gmail.com & 206524103@ukzn.ac.za

[1]Professor Onisimo Mutanga Email: MutangaO@ukzn.ac.za, Tel: +27 (0) 332605779 / Fax: +27 (0) 332605344

[2] University of Namur / Department of Biology, Research Unit in Environmental Biology, Rue de Bruxelles, 61 B-5000 NAMUR (Belgium), 0ffice phone +32-81724362, Email: jean-claude.micha@fundp.ac.be www.fundp.ac.be

1. Introduction

Developing countries are often characterized by steeply 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, Murshed-E-Jahan and Pemsl, 2011, Prein, 2002).

These challenges can be at least partially addressed by applying innovative systems of production (intensive or semi-intensive) with new agrarian technologies. The situation in Rwanda, with 2.82% annual population increase is no exception. Over 90% of Rwandan poor people live in rural areas, experiencing serious lack of animal protein and are considered food poor (MINECOFIN, 2007, NISR, 2010, Wise, 2004).

However, Rwanda has various advantages that are likely to favour the IAA system. These assets include an annual temperate and diversified climate, abundant rainwater, cheap and abundant labour. 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 type of innovative technological development with which this research is concerned is the Integrated Rabbit-Fish-Rice (IRFR) system. In the IRFR system, rabbit droppings (from rabbit hutches built over ponds) fertilise pond water and boost plankton production for the consumption of fish, and the enriched fishpond water by rabbit droppings with fish feces, fertilise rice field through irrigation system.

The overall objective of this study is to contribute to the development and optimisation of the complex integrated system in order to increase food production through the synergies of integrated farming practices such as the IRFR system that, we believe, suit resource-poor rural farmers, and promise both sustainable in management and environmentally friendly.

2. Material and Methods

Three experiments on rabbit-fish-rice system were carried out between 2008 and 2010, and one on rabbit-fish before, at the Rwasave fish farming and research station (SPIR / NUR) of the National University of Rwanda (NUR), Butare, Rwanda (geographic co-ordinates 02° 36’ 10’’ S and 29° 45’ 25’’ E and elevation of about 1625 m above sea level). All experiments were designed as shown on figure 2, and lasted between 4 and 5 months. Rabbit droppings (from rabbit hutches built over ponds) fertilise pond water and boost plankton production, and the enriched fishpond water fertilise rice field trough irrigation system, avoiding wastewater from being discharged into the environment.

The experiments lasted between four and five months and data were collected for water and soil quality assessment, and for growth and production of rabbit, fish, and rice. The water and soil nutrient quality was as assessed through analysis of physic-chemical parameters with a special emphasis on nitrogen and phosphorus nutrients.

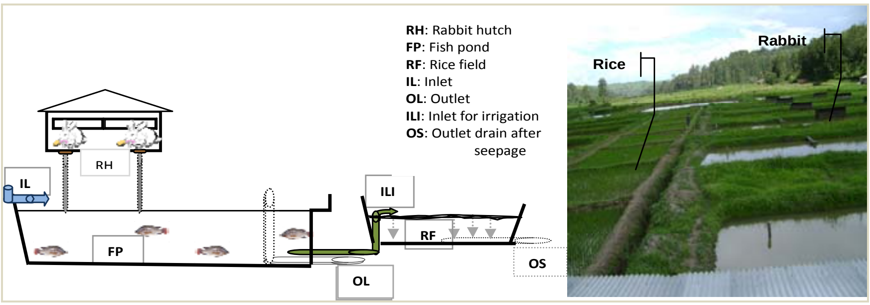

Figure 1. *A profile (photo and diagram) of the rabbit–fish–rice integrated system that constituted the study’s experiment conducted at the Rwasave Fish Culture Research Station. Note the connectivity between the rabbit hutch, the fishpond and the rice field. The pond is here drawn lengthwise.*

Total nitrogen (TN) and total phosphorus (TP) were also assessed in rabbit forage, rabbit dung and urine, fishpond and rice field soil, in fish, and in rice grain and straw to assess the flow of nutrients throughout the IRFR system. The growth and production parameters were determined on fish, rice and rabbit.

3. Results

3.1. Pond water and soil quality

Fishpond temperatures varied from 20.4 to 29.9°C, the pH was 6.5 to 8.4 while total alkalinity from 40 to 120 mg $CaCO_3.l^{-1}$ in the ponds undergoing the range of treatments and dissolved oxygen (D.O) varied from 1.4 to 10.5 $mg.l^{-1}$. The temperature, DO, pH, and total alkalinity as well as nutrients concentrations were not dependent significantly on fish density but the DO, the pH, and the temperature had always significantly higher values ($P<0.05$) in the afternoon than observed at dawn within the same treatment. Nutrients accumulated in the pond sediment and did increase at mid-term experiment (that is 90 days after rice transplanting) following by a decrease in all forms of phosphorus.

3.2. Resources and nutrients flow

The major sources of nutrient in this IRFR system were on-farm resources which accounted for 89.0% of the total N and 92.3% of the total P input and were mainly rabbit droppings, and pond effluents used to fertilise rice field. The water canal was a major off-farm contributor.

Analysis of the flow, by way of the mass balance of N and P nutrients, revealed that rabbit droppings 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 fish pond inputs, raising N and P concentration from 0.21 to 3.16 $mg.l^{-1}$ of TN and 0.01 to 0.66 $mg.l^{-1}$ of TP. 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 $P.ha^{-1}$) dependent on fish stocking density.

3.3. Optimum rabbit density

The range of densities that showed good DO, low concentration of inorganic nitrogen (nitrites and ammonia), and the highest NFY contained rabbit density of 800 to 1200 $rabbits.ha^{-1}$ of pond considered as the optimal rabbit density (Table 1).

Table 1. *Variation of Dissolved oxygen, ammonia, plankton biomass, fish yield and fish survival according to rabbit density and related dung excreted into fish pond*

Rabbits density (rabbits.ha^{-1})	Rabbit solid dung (kgDM.$ha^{-1}.d^{-1}$)	Dissolved oxygen mg.l^{-1}	Ammonia mg.l^{-1}	Plankton biomass µgChla.l^{-1}	Net fish yield (NFY) kg.$ha^{-1}.y^{-1}$	Fish survival rate (SR) %
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}
$LSD_{0.05}$		*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

3.4. Profitability, and fish and rice performance

3.4.1. Fish growth and production

Production parameters (total fish biomass, yield, and net fish yield) were dependent on fish density while growth parameters were inversely dependent as shown on table 2.

Table 2. *Growth and production performance of Nile tilapia stocked at 1 and 3 fish.m^{-2} 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).*

Growth performance		Treatments			
		PT1	PT2	$LSD_{0.05}$	P_{value}
Initial mean weight	g.$fish^{-1}$	32.76 ± 9.5	32.76 ± 9.50		
Final mean weight	g.$fish^{-1}$	104.31 ± 4.21^{a}	70.70 ± 1.65^{b}	*7.25*	*<.001*
Specific growth rate	% .d^{-1}	1.03 ± 0.04^{a}	0.69 ± 0.02^{b}	*0.06*	*<.001*
Daily weight gain	g.d^{-1}	0.64 ± 0.04^{a}	0.34 ± 0.01^{b}	*0.06*	*<.001*
Survival rate	%	88.50 ± 14.9^{a}	89.19 ± 4.40^{a}	*24.91*	*0.94*

Total biomass	kg	38.13 ± 6.20^{a}	77.56 ± 5.16^{b}	*12.93*	*<.001*
Yield	$kg.ha^{-1}$	953.3 ± 89.4^{a}	1938.9 ± 74.5^{b}	*3.23*	*<.001*
Net fish	$kg.ha^{-}$	2033.4 ± 191.6^{a}	3255.9 ± 151.4^{b}	*7.2*	*0.007*

PT1: Pond treatment with 1 $fish.m^{-2}$; **PT2**: Pond treatment with 3 $fish.m^{-2}$; **-$g.d^{-1}$**: gram per day; **-$kg.a^{-1}.yr^{-1}$**: kilogram per are (100 m2) per year. Values are means ± SE of three fish ponds for each treatment. Different superscript letters within the same row denote statistically significant differences ($P<0.05$).

3.4.2. Rice production performances

No significant differences was found between rice treatments ($P>0.05$). Rice field fertilized by NPK and urea showed slightly lower yield (5.79 $t.ha^{-1}.crop^{-1}$) but higher rice straw yields (10.79 $t.ha^{-1}.crop^{-1}$) than rice yield in fields fertilized by effluents (5.87 $t.ha^{-1}.crop^{-1}$). This advocates the potential replacement of inorganic fertilizers by fertilized fishponds effluents.

3.4.3. Cost-benefit analysis

All economic returns were dependent significantly ($P<0.001$) on fish density. The IRFR with highest fish density realized US$ 208, 132, and 30 of net return for IRFR-3$fish.m^{-2}$, IRFR-1$fish.m^{-2}$, and rice alone respectively, on 400 m^2 fishpond integrated to 90 m^2 rice field.

4. Discussion

4.1. Optimum rabbit density, Resources and nutrients flow and water quality

Since in this study, inorganic nitrogen did not reach highly toxic levels and chlorophyll *a* (chl *a*) was positively correlated ($r = 0.7247$; $P = 0.006$) to excreted rabbit dung, performed yield remained the key parameter for optimal density determination. Based on water quality parameters, the plankton and fish production, data in table 1 allow therefore for considering the density of 800 to 1200 rabbits as optimal because they provided the highest fish yield and best environment for fish growth, and at a higher density than this, fish yield began to decrease. This is in accordance with statement that fish biomass and fish SGR are correlated with high release of nutrients and fish yield with phytoplankton and primary production (Azim et al., 2001, Garg and Bhatnagar, 2000).

The main source of nutrients in the system was on-farm resources dominated by rabbit droppings which contributed for about 27% of the N and 79% of the P, fertilising the pond water at a rate of 3.98 kg N and 1.94 kg $P.ha^{-1}.d^{-1}$. This rate is higher than that (1.75 kg N and 0.39 kg $P.ha^{-1}.d^{-1}$) reported in an integrated Nile tilapia cage-cum-pond system (Yi et al., 2003) where tilapia were fed pellet feed. Earlier similar observations (Nhan et al., 2008, Prein, 2002, Xiuzhen, 2003) stated that an increase in pond production depends on on-farm resources, mainly livestock wastes, plant remnants, and by-products. In this research, Tilapia were able to recover 18.5-37.6% N and 16.9-34.3% P of the total nitrogen and phosphorus inputs, which is higher than that recovered by tilapia (12.75% N and 14.27% P of the waste in an integrated catfish-tilapia cage polyculture (Yi and Lin, 2000) while in 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).

The overall water quality parameters always ranged within acceptable limits for tilapia aquaculture. No significant differences among various fish stocking rates ($P>0.05$) were found for most physic-chemical water quality parameters. Higher concentrations of SRP and nitrates than these ones were recorded for tilapia ponds and / or tanks but still density dependant (Breine et al., 1996, Long and Yi, 2004, Yi et al., 1996).

4.2. Nile tilapia and rice performances and profitability

In this IRFR system, rabbit droppings led to common fish DWG for *O. niloticus* when fed various pellets for fish; 0.23 – 0.47 $g.d^{-1}$ (Yi et al., 1996, El-Shafai et al., 2007). Net fish yield (NFY) were strongly related to fish density ($R^2 = 0.9471$, $P<0.001$ for yield); the highest fish density pond's yield (1,938.92 $kg.ha^{-1}$) being close to that (2,082 $kg.ha^{-1}$) obtained when the fish were fed an azolla diet (28% crude protein) and stocked at 3 $fish.m^{-2}$ (Abou et al., 2007), and to 2,479.5 $kg.ha^{-1}$ for tilapia fed commercial pellet (El-Shafai et al., 2007). Possible deterioration of water quality as caused by high stocking density (Pankhurst et al., 1997, Yi et al., 1996) was associated with the negative correlation of fish growth to fish density observed also in the current study. The mean rice yields varying between 5.44 and 5.87 $t.ha^{-1}.crop^{-1}$ in the three treatments were not significantly different (P>0.05). 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). Rice yields are typically ranged from 2 to 5 $t.ha^{-1}.crop^{-1}$ (Frei and Becker, 2005) in an integrated system. In this study, performed yields demonstrated the ability of rabbit droppings to completely and successfully replace inorganic fertilizers.

Total investment costs and financial returns were density dependent in this IRFR as also reported by Lala I.P. Ray (2010) in concurrent rice-fish. The net return increased in RFR-1f and RFR-3f by 343.9% and 596.9% respectively over that of rice monoculture (RA). The RFR-3f also increased the net revenue over the RFR-1f's one by 57.0%. The increase revenue over rice monoculture is higher than various reports. Ofori et al. (2005) found the percentage increase ranged from 5 to 11% in concurrent rice-fish while Yaro et al. (2005) observed a weak effect and reported 4.6% increase of rice yield in rice-fish culture over rice monoculture.

5. Conclusion

The study advocated the potential adaptation of rabbits to wetland conditions and the role of rabbit droppings as organic fertilizers in providing a better environment for *O. niloticus* production (less turbidity, good levels of dissolved oxygen and inorganic nitrogen, as well as plankton development). The optimal rabbit density would be 800 – 1200 $rabbits.ha^{-1}$ of pond stocked with the best fish density three $fish.m^{-2}$ for sustainable IRFR system.

On-farm resources mainly rabbit droppings accounted for up to 27% N and 79% P of the total nitrogen and phosphorus in total inputs fertilizing fishpond at a rate of 3.98 kg N and 1.94 kg P. $ha^{-1}.d^{-1}$. This fertilisation led to a net fish yield of 2.03 – 3.26 $t.ha^{-1}.yr^{-1}$, and the effluent-rich led to 5 – 6 $t.ha^{-1}.crop^{-1}$ rice yield, occasioning an economic return increase of up to 597% over that of the rice inorganically fertilised thus substantiating the sustainability of the system.

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

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