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ORIGINAL RESEARCH

Valorization of various sources of rabbit manure in agro-piscicultural system in Benin (West Africa): dynamics and effect of mineralization upon quality of fresh water

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Abstract
Purpose Rising demand of fish generates various pressures on aquatic ecosystems, causing its deterioration and the loss of its biodiversity. With the aim of a better management and fish production in a salubrious environment, this study proposes the utilization of organic fertilizers from rabbit manure.
Methods The treatments consisted of manure of rabbits fed with: manufactured diet (T_1), improved diet with *Ipomea aquatic* (T_2), improved diet with *Elaeis guineensis* (T_3), and improved diet with *Panicum maximum* (T_4). Indeed, experimental design was a completely randomized block design with three replications. 6 g in 10 L of water from the different manures from each diet was followed during 50 days. Various nutrients were measured.
Results After the mineralization process, the best manure which released more nutrients was T_4 with measured proportions of N-NO_2^-, N-NO_3^-, N-NH_3, P-PO_4^{3-}, Ca^{2+}, Mg^{2+}, K^+, and suspended matter being 0.06 ± 0.0, 0.38 ± 0.1, 0.85 ± 0.1, 8.27 ± 0.9, 12.11 ± 0.8, 4.47 ± 0.3, 3.02 ± 0.2, and 140.78 ± 18.6 mg/L, respectively. The highest content of phosphorus and nitrogen was recorded in T_4 and T_2, respectively. The principal component analysis showed a positive correlation between P-PO_4^{3-}, Ca^{2+}, Mg^{2+}, MES, conductivity, and salinity during mineralization.
Conclusion Manure from rabbits fed by an improved diet with *P.* maximum (T_4) was recommended for agro-piscicultural production system.

Keywords Rabbit manure · Mineralization · Water · Nutrient · Agro-piscicultural

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Introduction

Today, aquaculture is increasingly developing in the world (e.g., over 60% of the total fish production in China) despite the serious environmental problems that may occur (Li 2002; Lazard 2014). Although it remains under developed in most parts of Africa (Lazard 2014), its production has increased in recent years, compared to other livestock such as pigs, cows, and poultry (FAO 2010). Similarly, the strong fish demand has increased with population growth (FAO 2012). However, such demand has led to the deterioration of natural resources, especially quality, with the loss of its biodiversity (Moura E Silva et al. 2016). Fish farming could play a key role in facing the challenge of rising demands of animal proteins (Kaushik 2014). Strengthening the sector depends upon the efficient use of organic fertilizers of animal origin for an optimal primary production in fish conventional systems (Goulding et al. 2008). Indeed, the burst of optimal and sustainable fish farming must necessarily use a dynamic resource available such as organic fertilizers (FAO 2012). Thus, organic fertilizer use is a suitable alternative for agricultural activities to improve fish productivity and yields (Pucher et al. 2012; Bokossa et al. 2014a). Steinbronn (2009) showed that aquaculture production contributes significantly to food security, generates income, and plays a significant role in farmers' livelihood strategies. According to Wilkins (2008), the practice of integrated systems (animal and plant production) would give an economic and ecological efficiency in operations. Likewise, Wilkins (2008) and Lemaire et al. (2013) revealed that this practice would reduce the loss of nitrogen, phosphorus, and carbon to the environment and might limit the use of chemical fertilizers. Although animal manures have been investigated in zooplankton production in West African countries (e.g., Akodogbo et al. 2015), to our best knowledge, no study has dealt with the nutrients released in water from manure of rabbits.

The aims of our study were to (i) determine the effect of the diet on manure quality and (ii) assess the water quality and nutrient dynamics during the mineralization process.

Materials and methods

Experimental site

The experiment was conducted from June to August 2016 at a site (6°24′53.3″ N; 2°20′18.5″E; altitude 9 m above sea level) located at the University of Abomey-Calavi Benin. The area is characterized by a sub-equatorial climate with two rainy seasons (March to end of July and mid-September to November) and two dry seasons (August to mid-September and December to March).

Rabbits (*Oryctolagus cuniculus*) feeding and manure collection

The rabbit manure was obtained from 36 8-month-old local breed young rabbits. Four triplicates including a control were formulated. They were placed in 12 galvanized iron cages of 1 m length, 0.5 m wide, and 0.5 m height each. The cages were randomly placed in a hangar. Each cage was equipped by a manger and a trough. Nets of mesh (0.1 mm) were suspended to the bottom of the cages to collect rabbit manures. Rabbit manures were stored in bags of 25 kg.

Four diets were involved during the study period: classic manufactured (T_1), improved diet with *Ipomea aquatic* (T_2), improved diet with *Elaeis guineensis* (T_3), and improved diet with *Panicum maximum* (T_4). T_1 was manufactured locally by a veterinarian society service. Its chemical composition comprised: proteins (raw material) 17%, calcium ≥1.14%, total phosphorus ≥0.8%, lysine ≥0.75%, methionine + cystine ≥0.6%, crude fat ≥2%, crude fiber ≥14%, and ≥0.1% flavomycine.

The compositions of the three other diets were:

T_2 Tuber cassava 2%, born bran 20%, palm kernel meal 10%, soy bran 10%, cottonseed meal 15%, shell 2%, distillers grains 20%, *Azolla filiculoïdes* 10%, brewer's yeast 5%, *Ipomoea aquatica* 15%, and salt 1%.

T_3 Cossette cassava 2%, corn bran 25%, palm kernel meal 15%, soy bran 5% cottonseed meal 10%, shell 2%, distillers grains 15%, *Azolla filiculoïdes* 5%, brewer's yeast 10%, *Elaeis guineensis* 10%, and salt 1%.

T_4 Cossette cassava 2%, corn bran 30%, palm kernel meal 10%, soy bran 10%, cottonseed meal 5%, shell 2%, distillers grains 10%, *Azolla filiculoïdes* 5%, brewer's yeast 15%, *Panicum maximum* 10%, and salt 1%.

Experimental design and water enrichment process

The experimental design was a completely randomized block design with three replications. The treatments consisted of the different types of manure collected from the experimental cages. The rabbit manures were grounded into nylon mosquito toils with a mesh size of 1 mm. For each treatment, 12 nylon mesh bags containing 6 g of dried manures were tied and suspended in 10 L of water (Mascha et al. 2010; Agadjihouèdé et al. 2011; Qiu et al. 2012; Bokossa et al. 2014a). A total of 150 plastic buckets (10 lots × 15 buckets) were used in the experiment. Each manure nylon mesh bags were placed randomly within 12 buckets. Three control (no fertilizer) buckets per lot were used. They were used for calibration purpose (i.e., correct the values form fertilized buckets). Half of the ten lots were sampled every 3 days, while the remaining was sampled every 7 days to take into account the labile and resistant fractions, respectively. At the sampling date, 12 nylon bags containing manures were collected, as well as 15 water samples of 500 ml each (including three controls). Water samples were then sent to the laboratory for analysis.

In all the buckets, temperature, pH, conductivity, dissolved oxygen, total dissolved solids (TDS), and salinity were measured ''in situ" at the sampling days with a multiparameter probe (softer version/2015 2138 SN-ODEON CALYPSO; ±0.1 °C sensitivity).

Mineralization process and water analysis

Water samples were stored in a refrigerator at 4 °C to evaluate the released nutrients during the mineralization process. Analyses included the determination of suspended solids, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$, $N\text{-}NH_3$, $P\text{-}PO_4^{3-}$, Mg^{2+}, K^+, and Ca^{2+} contents. Their measurement was performed using a molecular absorption spectrophotometer (DR 2800). After homogenization of the mixture, the suspended solids were measured at a wavelength of 810 nm. The ammonia combines with chlorine to form monochloramine which reacts with salicylate to form 5-aminosalicylate. $N\text{-}NH_3$ content was obtained at 655 nm. Regarding

Table 1 Chemical characteristics of rabbit manure regarding the composition of the diet used to feed the animal

Treatment	Nutrient content (mg/L)			
	N	P	K	N:P
T_1	12.33 ± 0.01c	1.03 ± 0.00c	1.66 ± 0.05b	11.97 ± 0.07bc
T_2	16.34 ± 0.03a	1.04 ± 0.00bc	2.19 ± 0.23a	15.66 ± 0.15a
T_3	14.02 ± 0.58b	1.06 ± 0.01b	0.79 ± 0.04c	13.23 ± 0.64b
T_4	15.02 ± 0.58ab	1.26 ± 0.00a	0.84 ± 0.02c	11.89 ± 0.44c
CV (%)	14.43	1.09	1.37	13.19

CV coefficient of variation

Means followed by the same letter are not significantly different ($p > 0.05$) according to the LSD. Treatments' description: *T_1* manufactured diet, *T_2* improved diet with *Ipomea aquatica*; *T_3* improved diet with *Elaeis guineensis,* and *T_4* improved diet with *Panicum maximum*

$N\text{-}NO_3^-$, the cadmium reduces nitrate to nitrite sample. The nitrite ion reacts with sulfanilic acid to form an intermediate diazonium salt. The nitrite present in the sample reacts with sulfanilic acid to form an intermediate diazonium salt. This combines with chlorotropique acid to produce a pink-colored complex, whose intensity is directly proportional to the nitrite concentration in the solution. The reading was obtained at 507 nm. $P\text{-}PO_4^{3-}$ was measured by the colorimetric method using blue ammonium molybdate reagent; measurements were realized at a wavelength of 880 nm. K^+, Ca^{2+}, and Mg^{2+} concentrations were determined by atomic absorption spectrophotometry (Rodier et al. 2012).

Data Analysis

The SAS software (SAS Version 9.2, SAS Institute Inc., Cary, NC, USA) was used for data analysis. The ANOVA was performed on the nutrient released in water during the decomposition process using time and treatments as factors. Main effects and interactions between treatments were assessed for significance levels, and separation was conducted using Fisher's protected LSD test. All levels of significance were set at p value <0.05. A principal component analysis (PCA) was also performed to assess the correlation between different parameters. This was done using the STATISTICA software (Statsoft inc., Tulsa, OK, USA).

Results

Influence of the diet on manure quality

The nutrient content from the manure from rabbits fed with the different diets are presented in Table 1. The potassium, phosphorus, and nitrogen contents were significantly different ($p < 0.05$) between treatments. N:P:K ratios from T_4, T_3, T_2, and T_1 were, respectively, 18:2:1, 18:1:1, 8:1:1, and 7:1:1. For nitrogen content, treatments can be classified as $T_2 > T_4 > T_3 > T_1$, while for the phosphorus content, the classification was $T_4 > T_3 > T_2 > T_1$. Regarding N:P ratios, the order was $T_2 > T_3 > T_1 > T_4$ (Table 1). Overall, the manures from rabbits fed with improved diet with *Panicum maximum* had significantly high phosphorus content ($p < 0.05$). Whereas manures from rabbits fed with improved diet with *Ipomea aquatica* recorded the highest nitrogen content.

Water quality and nutriment dynamics

The ANOVA (Table 2) showed that the diet had significant influence on nutrient contents including $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_3$, $P\text{-}PO_4^{3-}$, Mg^{2+}, K^+, and suspended solid ($p < 0.0001$), and Ca^{2+} ($p < 0.05$). However, no significant effect was noticed for the in situ parameters ($p > 0.05$) (Table 2). The time significantly influenced all the measured parameters ($p < 0.05$), thus showing that nutrient and "in situ" parameters changed with time. The different nutrient dynamics depended on the diet: the treatment–time interaction was significant for all nutrients ($p < 0.0001$), except $P\text{-}PO_4^{3-}$, whereas it was not for the "in situ" parameters.

The physicochemical quality of water was affected by the release of the various fertilizing elements from rabbit manures (Table 3). The increase of conductivity, temperature, pH, dissolved oxygen, dissolved total solids, and salinity was found for all the treatments during the process of the enrichment of water following the decomposition of rabbit manures during 50 days of the experimentation in a progressive way. However, no significant difference between the treatments was found at the end of the experiment (Fig. 1; Table 3). Indeed, the temperature ranged from 29.66 ± 0.3 to 29.81 ± 0.3 in all the treatments. The conductivity was 240.85 ± 14.5, 239.72 ± 14.0, 238.98 ± 13.5, and 237.58 ± 14.1 µS/cm in treatments T_4, T_2, T_3, and T_1, respectively. A high increase of conductivity was recorded in the treatments resulting from

Table 2 Value of F and level significance of variance analysis (ANOVA), various modes on days, and physicochemical parameters

Sources of variation	ddl	Fisher's values													
		NO_2^-	NO_3^-	NH_3	PO_4^{3-}	Ca^{2+}	Mg^{2+}	K^+	SS	T °C	02	pH	Cond	TDS	Sal
Repetitions	2	0.14 ns	1.67 ns	0.16 ns	11.04***	1.23 ns	3.40*	0.73 ns	5.24***	3.38*	0.40 ns	10.06***	2.08 ns	2.21 ns	3.77*
Diet	3	8.46***	2.52 ns	158.80***	18.47***	3.01*	9.55***	3926***	48.19***	1.07 ns	0.28 ns	0.17 ns	0.19 ns	0.05 ns	0.19 ns
Days	9	249.10***	34.69***	3.65*	108.72***	65.66***	42.15***	825***	13526***	261.02***	88.51***	367.1***	243.8***	265.4***	130.4***
Diet*days	27	4.27***	2.84***	4.54***	1.19 ns	2.26*	3.29***	5.04***	6.97***	0.78 ns	0.66 ns	0.31 ns	0.55 ns	0.74 ns	0.83 ns

ns $p > 0.05$

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.0001$

tested diets (T_4, T_3, and T_2) compared to those from the standard diet (T_1). That could be explained by a higher release of ortophosphate, salinity, suspended solids, calcium, and magnesium in the improved diets (Table 3). There was no significant difference between treatments for pH, dissolved oxygen, TDS, and salinity. This result can be explained by similar experimental condition and microorganism activity in the buckets.

The different types of manure have induced significant increase in N fractions (N-NH_3, N-NO_3^-, and N-NO_2^-) at the end of experiment. The K^+, Ca^{2+}, Mg^{2+}, P-PO_4^{3-}, and suspended solid contents in the water at the end of the decomposition process of the rabbit manures fed with different diets had also significantly increased ($p < 0.05$) as indicated by the large amount of released nutrients.

According to the observed nutrient dynamics (Table 3), nitrites increased during the first week before decreasing in the last weeks of the experimentation in all the treatments generally. Such a dynamic was noticeable particularly in T_1, T_2, and T_3. Mean NO_2^- values in the different treatments increased from 0.0 ± 0.0 mg/L (T_1) to 0.1 ± 0.0 mg/L (T_4) during 50 days. These variations can be explained by the microbial activity which influences the permanent availability of nitrites. The reductions of nitrates in the treatments were revealed from the 9th days. These reductions were related to the ambient temperature. Indeed, when temperature became high, biochemical reactions were very important affecting nitrogen transformation or bacteria denitrification. The highest N-NO_3^- concentrations were obtained in T_2 (0.38 ± 0.1 mg/L) followed by T_4 (0.33 ± 0.0 mg/L). During the experiment, the average N-NH_3 content ranged from 0.43 ± 0.0 mg/L in T_1 to 1.62 ± 0.0 mg/L in T_4. However, significant decreases by 3.67, 1.9, and 1.26 times were noticed in ammonium concentrations in the manure from treatments T_1, T_2, and T_3, respectively, compared to T_4. This is related to the equilibrium constant which can be favourable to a massive loss of nitrogen as ammonia gas or favourable to storage in water as NH_4^+. In the rabbit manures, the volatilization process of ammonia consisted in the transfer of ammonia gas in the immediate atmosphere from ammonia in manure decomposing in water during experimentation. The concentration of orthophosphate, which was 10.83 ± 1.0 mg/L in the T_4 treatment, was 1.33, 1.30, and 1.2 times higher, respectively, than in treatments T_1, T_2, and T_3 ($p < 0.05$). Tendency similar trend was practically noticed with the other elements such as Ca^{2+}, Mg^{2+}, and K^+. This result revealed the richness of T_4 compared to the others treatments. We also noticed a rapid increase of K^+ concentrations in T_2 contrary to T_1; while T_3 and T_4 indicated during the first 12 days of experiment a rapidly mineralizable labile fraction of organic matter even from this time to the end of the experiment, a readily degradable fraction was found in rabbit manure.

Table 3 Effect of nutrients released from the different manure on water quality

Treatment	Days	Nutrient content							
		N-NO_2^- (mg/L)	N-NO_3^- (mg/L)	N-NH_3 (mg/L)	P-PO_4^{3-} (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^+ (mg/L)	SS (mg/L)
T_1	3	0.01 ± 0.00c	1.01 ± 1.01a	0.83 ± 0.83a	3.33 ± 3.33b	5.87 ± 5.87d	2.72 ± 2.72ef	1.74 ± 1.74ba	5.23 ± 5.22d
	6	0.14 ± 0.01a	1.12 ± 1.12a	0.89 ± 0.89a	4.14 ± 4.14b	6.89 ± 6.89dc	2.84 ± 2.84ef	1.84 ± 1.84ba	19.59 ± 19.58d
	9	0.15 ± 0.00a	0.33 ± 0.02b	0.71 ± 0.04b	5.57 ± 7.71b	10.10 ± 0.14cb	3.55 ± 0.16edf	1.03 ± 0.10b	82.71 ± 0.94c
	12	0.08 ± 0.07ab	0.13 ± 0.01dc	0.07 ± 0.05e	2.84 ± 0.46b	7.68 ± 0.65cbd	2.27 ± 0.26f	1.06 ± 5.56b	117.00 ± 0.06c
	15	0.01 ± 0.00c	0.20 ± 0.04c	0.22 ± 0.01d	3.25 ± 0.51b	8.53 ± 0.32cbd	4.43 ± 0.15bdc	2.71 ± 0.39a	92.67 ± 19.67c
	22	0.01 ± 0.00c	0.14 ± 0.00dc	0.30 ± 0.03dc	11.50 ± 0.45a	14.79 ± 2.27a	4.44 ± 0.26bdc	2.39 ± 9.70a	184.33 ± 0.52b
	29	0.03 ± 0.00c	0.06 ± 0.04de	0.33 ± 0.02c	12.64 ± 1.85a	15.86 ± 1.29a	4.02 ± 0.47edc	1.69 ± 0.59ba	218.67 ± 10.91ba
	36	0.00 ± 0.00c	0.01 ± 0.00e	0.34 ± 0.02c	12.64 ± 1.85a	10.92 ± 1.71b	6.23 ± 1.06a	1.76 ± 13.66ba	237.33 ± 0.61a
	43	0.00 ± 0.00c	0.05 ± 0.04de	0.33 ± 0.02c	12.44 ± 1.85a	16.06 ± 1.29a	5.35 ± 0.92bac	1.69 ± 0.59ba	246.67 ± 24.06a
	50	0.00 ± 0.00c	0.06 ± 0.04de	0.33 ± 0.02c	12.64 ± 1.85a	15.86 ± 1.29a	5.68 ± 0.74ba	1.69 ± 0.59ba	248.67 ± 24.06a
	Means T_1	0.04 ± 0.01C	0.31 ± 0.07AB	0.43 ± 0.04D	8.10 ± 0.86B	11.25 ± 0.77B	4.15 ± 0.27A	1.76 ± 0.14D	145.28 ± 16.95A
T_2	3	0.01 ± 0.00d	1.01 ± 0.03c	1.05 ± 0.00bac	2.71 ± 0.29c	6.26 ± 0.41c	2.27 ± 0.26e	2.23 ± 0.05cd	10.60 ± 1.78e
	6	0.18 ± 0.02b	1.23 ± 0.16a	1.27 ± 0.11a	3.83 ± 0.23cb	9.56 ± 0.90b	3.09 ± 2.34ed	2.22 ± 0.05cd	10.68 ± 0.52ed
	9	0.24 ± 0.01a	0.34 ± 0.05a	1.24 ± 0.15ba	5.49 ± 0.60b	8.74 ± 0.18b	2.40 ± 0.11e	1.44 ± 0.25d	66.19 ± 3.59e
	12	0.12 ± 0.01c	0.38 ± 0.38ab	0.76 ± 0.76bdc	3.05 ± 3.05c	7.96 ± 7.96cb	4.35 ± 4.35cd	6.10 ± 6.10a	63.33 ± 63.33cd
	15	0.01 ± 0.00d	0.12 ± 0.02c	0.43 ± 0.02d	2.37 ± 0.66c	7.96 ± 0.46cb	2.98 ± 0.34ed	3.78 ± 0.86b	133.67 ± 34.43ed
	22	0.01 ± 0.00d	0.18 ± 0.08c	0.42 ± 0.06d	13.76 ± 0.68a	16.10 ± 1.01a	5.45 ± 0.38cb	3.37 ± 0.27cb	152.33 ± 21.69cb
	29	0.02 ± 0.00d	0.11 ± 0.07c	1.10 ± 0.14bac	12.67 ± 1.22a	16.07 ± 1.01a	5.83 ± 0.88b	2.67 ± 0.14cbd	235.33 ± 29.47b
	36	0.00 ± 0.00d	0.24 ± 0.06c	0.61 ± 0.34dc	13.67 ± 1.22a	16.09 ± 1.02a	7.39 ± 0.49a	3.05 ± 0.17cb	175.00 ± 13.07a
	43	0.00 ± 0.00d	0.11 ± 0.07c	1.17 ± 0.30ba	12.47 ± 1.22a	16.27 ± 1.01a	5.83 ± 0.88b	2.67 ± 0.14cbd	281.00 ± 14.64b
	50	0.01 ± 0.00d	0.11 ± 0.07c	0.50 ± 0.05d	12.67 ± 1.22a	16.07 ± 1.01a	5.16 ± 0.58cb	2.67 ± 0.14cbd	279.67 ± 9.76cb
	Means T_2	0.06 ± 0.01A	0.38 ± 0.07A	0.85 ± 0.07C	8.27 ± 0.93B	12.11 ± 0.78AB	4.47 ± 0.33A	3.02 ± 0.24B	140.78 ± 18.64A
T_3	3	0.03 ± 0.00d	0.80 ± 0.35a	0.77 ± 0.51b	5.07 ± 0.88c	8.20 ± 0.86b	1.67 ± 0.14e	2.16 ± 0.16b	10.95 ± 1.15d
	6	0.18 ± 0.02b	0.42 ± 0.26ab	1.14 ± 0.18ba	5.61 ± 0.41c	9.89 ± 0.22b	2.72 ± 0.11d	2.28 ± 0.14b	30.93 ± 3.08dc
	9	0.26 ± 0.03a	0.19 ± 0.04b	1.32 ± 0.05a	5.59 ± 0.64c	9.09 ± 0.47b	2.98 ± 0.04dc	1.44 ± 0.20c	44.49 ± 9.57cbd
	12	0.10 ± 0.00c	0.13 ± 0.00b	1.47 ± 0.06a	4.43 ± 0.84c	8.57 ± 0.36b	3.17 ± 0.16dc	2.28 ± 0.14b	48.00 ± 5.13cbd
	15	0.01 ± 0.00d	0.15 ± 0.01b	1.42 ± 0.06a	4.67 ± 0.48c	9.22 ± 0.85b	1.66 ± 0.28e	1.24 ± 0.20c	62.67 ± 14.74cb
	22	0.01 ± 0.00d	0.29 ± 0.05b	1.44 ± 0.02a	12.12 ± 0.30ba	14.40 ± 1.44a	5.05 ± 0.26a	3.31 ± 0.22a	77.00 ± 6.65b
	29	0.01 ± 0.00d	0.13 ± 0.11b	1.47 ± 0.03a	10.39 ± 2.01b	15.76 ± 0.69a	3.70 ± 0.50bc	3.41 ± 0.12a	153.33 ± 18.80a
	36	0.01 ± 0.00d	0.26 ± 0.04b	1.40 ± 0.05a	14.39 ± 1.69a	15.76 ± 0.47a	4.14 ± 0.28ba	3.36 ± 0.29a	170.67 ± 20.16a
	43	0.00 ± 0.00d	0.13 ± 0.11b	1.47 ± 0.03a	13.19 ± 1.69ba	15.96 ± 0.69a	4.92 ± 0.47a	3.41 ± 0.12a	151.33 ± 21.53a
	50	0.01 ± 0.00d	0.13 ± 0.11b	0.97 ± 0.02ba	13.39 ± 1.69ba	14.87 ± 0.69a	5.03 ± 0.41a	3.18 ± 0.02a	146.67 ± 20.33a
	Means T_3	0.06 ± 0.01A	0.26 ± 0.05A	1.28 ± 0.06B	8.88 ± 0.80B	12.17 ± 0.63AB	3.50 ± 0.24B	2.61 ± 0.15C	89.60 ± 11.11C

Table 3 continued

Treatment	Days	Nutrient content							
		N-NO_2^- (mg/L)	N-NO_3^- (mg/L)	N-NH_3 (mg/L)	P-PO_4^{3-} (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^+ (mg/L)	SS (mg/L)
T_4	3	0.01 ± 0.00d	0.81 ± 0.16a	1.41 ± 0.12e	3.51 ± 0.42e	6.25 ± 0.74f	1.72 ± 2.67e	3.04 ± 0.32bcd	10.67 ± 0.59 h
	6	0.35 ± 0.03a	0.44 ± 0.06bc	1.54 ± 0.05edc	4.88 ± 0.41de	8.74 ± 0.61fe	2.88 ± 0.05dc	3.47 ± 0.36bc	60.92 ± 5.38 g
	9	0.25 ± 0.01b	0.57 ± 0.02ba	1.65 ± 0.06bdc	7.30 ± 0.71c	10.32 ± 0.46de	3.55 ± 0.23c	2.07 ± 0.27d	78.85 ± 5.30ef
	12	0.12 ± 0.00c	0.19 ± 0.00cd	1.85 ± 0.04a	6.26 ± 0.31dc	9.21 ± 0.16e	4.68 ± 0.22b	2.78 ± 0.31dc	97.66 ± 4.09d
	15	0.01 ± 0.00d	0.15 ± 0.09d	1.74 ± 0.06ba	6.32 ± 0.23dc	12.06 ± 0.76dc	2.26 ± 0.07de	2.8 ± 0.45dc	76.00 ± 1.15f
	22	0.01 ± 0.00d	0.28 ± 0.08cd	1.87 ± 0.05a	16.40 ± 0.83ba	16.14 ± 1.12ba	4.58 ± 0.18b	4.22 ± 0.05ba	88.33 ± 4.63ed
	29	0.02 ± 0.00d	0.19 ± 0.09cd	1.72 ± 0.05bac	14.96 ± 0.80b	14.28 ± 1.08bc	3.64 ± 0.31c	3.84 ± 0.40bac	130.33 ± 4.40c
	36	0.01 ± 0.00d	0.32 ± 0.03cd	1.52 ± 0.04ed	17.76 ± 0.60a	18.24 ± 0.91a	6.42 ± 0.31a	4.10 ± 0.70ba	146.66 ± 4.63b
	43	0.00 ± 0.00d	0.19 ± 0.09cd	1.35 ± 0.02e	15.55 ± 0.81b	14.48 ± 1.08bc	6.34 ± 0.33a	3.84 ± 0.40bac	185.00 ± 1.15a
	50	0.02 ± 0.00d	0.19 ± 0.09cd	1.53 ± 0.04ed	15.42 ± 0.82b	14.28 ± 1.08bc	6.01 ± 0.03a	4.68 ± 0.11a	137.00 ± 2.88cb
	Means T_4	0.08 ± 0.02A	0.33 ± 0.04AB	1.62 ± 0.03A	10.83 ± 1.00A	12.40 ± 0.69A	4.21 ± 0.30A	3.48 ± 0.17A	101.14 ± 8.83B

For each treatment, mean values with the same lower case letter in a column indicate not statistically significant differences ($p > 0.05$) according to LSD test. For each column, mean values followed by the same capital letter indicate not statistically significant differences between treatments ($p > 0.05$) according to LDS test

SS suspended solid

Overall, T_4 released the higher concentrations of nutrients being able to be used for fish production systems by its contribution for primary production.

Classification of treatments according to their nutrient profile

Figure 2 depicts the results of the PCA. All the variables can be classified according to the main components which explained 66.13% of the information (51.61% for F1 and 14.52% for F2). The most correlated variables to F1 were: conductivity, orthophosphate, suspended solid, total dissolved solids (TDS), salinity, magnesium, and nitrate (Table 4). Among these variables, those who contribute most to F1 were two different groups: for the first group conductivity, orthophosphate, suspended solid, salinity, and magnesium which are highly correlated between each other and negatively to F1, since they define eigenvectors same direction, and for the second group composed only by the nitrate which was positively correlated with F1 (Fig. 2a). On F2, the most correlated variables are temperature, pH, and oxygen. However, some variables (potassium and ammonium) are near to centre of the factorial design, and their correlation is not certainly very strong. These variables are probably better explained by others minor components. Taking into account all the information provided by F1 and F2 (Table 4), the physicochemical parameters belonging to the axis F1, only orthophosphate was high and was at the origin of the mineralization, explaining the increase in conductivity, suspended solids, TDS, and salinity. The biochemical activity of degradation of the organic matter by microorganisms depends on the physical and chemical conditions of the environment. A temperature rise could increase P-PO_4^{3-}, Ca^{2+}, Mg^{2+}, SS concentrations, and salinity. Likewise, a rise in the temperature and pH is followed by an increase of nitrate concentration. Indeed, the fluctuation of temperature, dissolved oxygen, and pH modulate mineralization rate because of their key role on the microbial activity on organic matter.

Discussion

Diet and manure's nutrient content

The efficient uses of organic fertilizers necessitate a good knowledge of their nutrient contents. Nutrients released from organic manure constitute the key of the primary production. However, their excessive concentrations can negatively impact the aquatic environment (e.g., eutrophication). Therefore, it is essential to quantify their concentration in the aquatic environments to avoid such negative

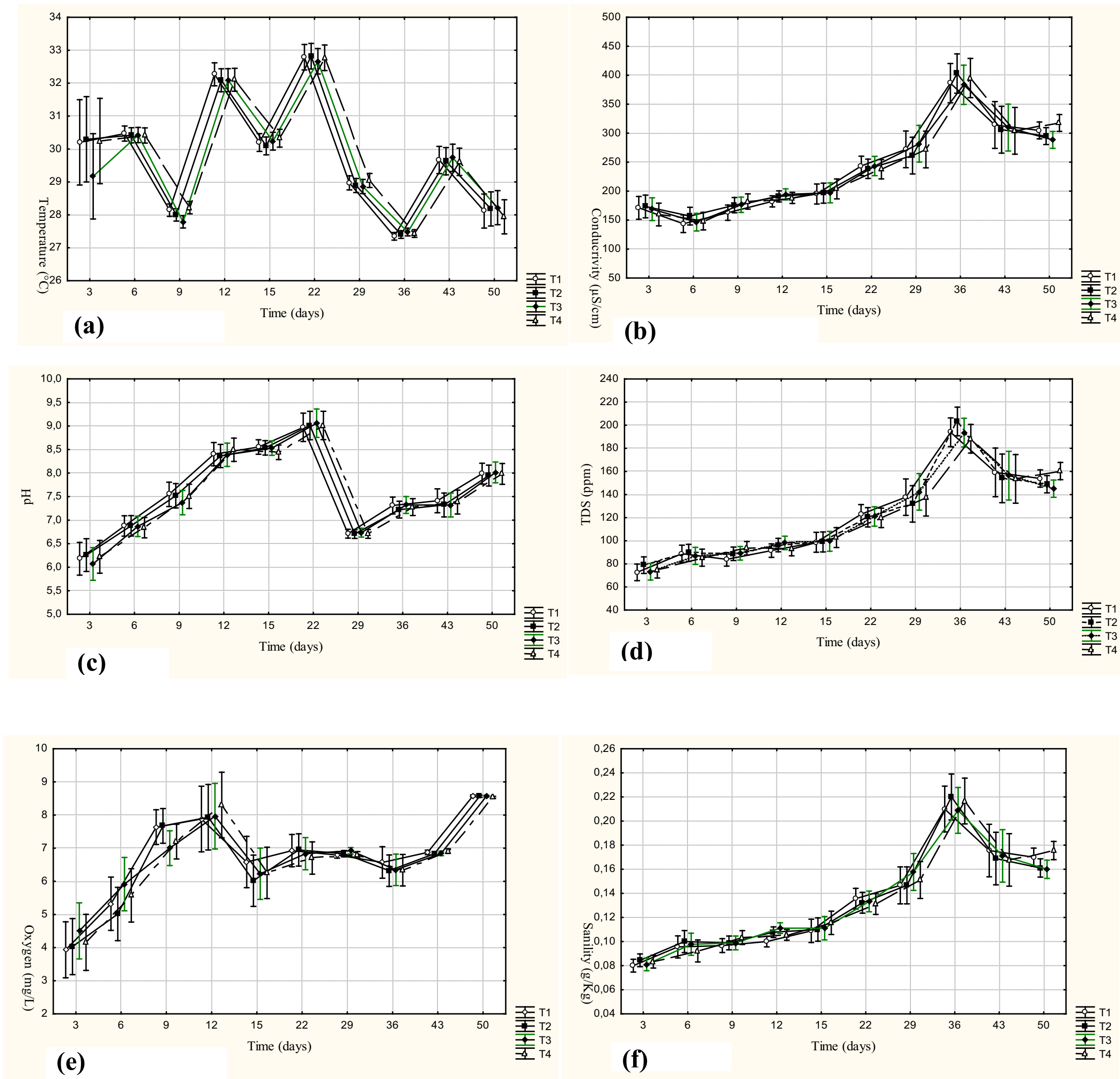

Fig. 1 Physico-chemical parameter of the various treatments according to time **a** temperature; **b** conductivity; **c** pH; **d** total dissolved solid (TDS); **e** oxygen; and **f** salinity. Treatments' description: T_1 manufactured diet, T_2 improved diet with *Ipomea aquatica*, T_3 improved diet with *Elaeis guineensis*, and T_4 improved diet with *Panicum maximum*

impacts or mitigate them. Our results showed that the nutrient content from the different types of rabbit manure varied qualitatively and quantitatively according to the tested diet. This result could be explained by the diet composition (nitrogen levels, phosphorus, potassium, calcium, magnesium, etc.). This is in line with Martinez-Ballestra et al. (2008) who noted that the concentrations of these nutrients in animal waste strongly depend on the composition of food rations. Rations are influenced by factors such as the species, type of digestion, chemical composition, and presence of secondary compounds (Mackie 2002; Michelland et al. 2012). The concentrations of 1.26 mg/L of phosphorus for T_4 and 16.34 mg/L of nitrogen for T_2 were higher than those found by Vodounnou et al. (2016), which were 0.011 mg/L for phosphorus and 0.025 mg/L for nitrogen in rabbit manures. This difference could be explained by the type of tested diets and rabbit species used in one hand, and the conservation process of these rabbit manures in the other hand. However, these results are lower than those obtained by Bokossa et al. (2014a) on manure from pigs fed with *Azolla* and rice bran. This difference is due to the composition of diets and digestibility of rations applied to monogastric animals. Indeed, rabbits have a complex digestive physiology compared to other herbivores and omnivores.

The value of the N:P ratio indicates which one between N and P is the limiting factor. According to rough nutrient balance estimation, the best ratio for sustainable aquaculture production was that obtained with treatment T_2 (N:P = 15:1 and N:P:K = 18:1:1), but N:P ratio was

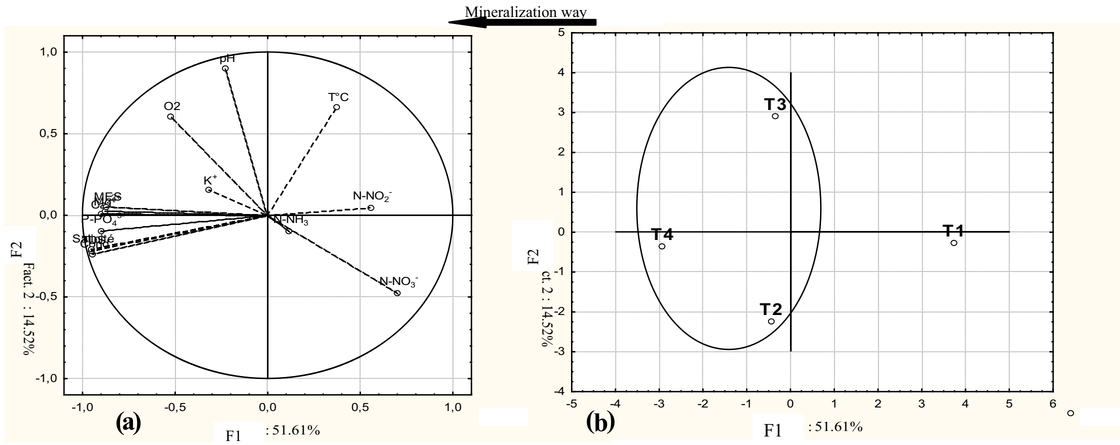

Fig. 2 Principal component analyses of treatments and their effect on water quality. **a** Correlation between chemical parameters; **b** classification of treatments

Table 4 Correlation coefficients between variables and axis principal

	Factorial axe 1	Factorial axe 2
$N\text{-}NO_2^-$	0.55	0.04
$N\text{-}NO_3^-$	0.69	−0.47
$N\text{-}NH_3$	0.11	−0.09
$P\text{-}PO_4^{3-}$	−0.90	−0.09
Ca^{2+}	−0.89	0.00
Mg^{2+}	−0.87	0.02
K^+	−0.31	0.15
SS	−0.87	0.04
T °C	0.37	0.66
O_2	−0.52	0.60
pH	−0.22	0.89
Cond	−0.94	−0.23
TDS	−0.94	−0.21
Salinity	−0.95	−0.20

between 10:1 and 20:1 for all treatments (Borchardt 1996). This ratio from our study confirmed the enrichment of T_4 treatment in phosphorus. These results are similar to those obtained by Güsewell and Verhoeven (2006) and Guckland et al. (2009), where N:P ratio was 16:1 during the decomposition of leaves and 11:1 in the soil, respectively.

Panicum maximum at 3 week age contains 32.3% calcium, 46.6% phosphorus, and 71% of magnesium (Oyenuga 1960). These high contents of magnesium and phosphorus in the form of orthophosphate contribute to their high growth, density, biomass, and net primary production (Rejmánková 2001; Cody et al. 2010). The high phosphorus content recorded in treatment T_4 would play a crucial role in phytoplankton production in fish net.

Effect of rabbit manure on nutrient dynamics and water quality

The experiment took place during the dry season with temperature fluctuating between 28 and 30 °C. It had played an important role in organic matter mineralization, but also induced a good solubility and diffusion of gases such as oxygen in water (Belghiti et al. 2013; Bokossa et al. 2014b). The speed of oxygen diffusion depends for a large part on the contact area between air and water. The quantitative importance of this process depends on the temperature, light, and richness in nutrients. After the water fertilization was achieved, 3 day latency time (enzymatic adaptation) was observed during which values of chemical parameters did not varied a lot. The pH remained around 6 in all the treatments. Microbial activity started thus after these 3 days and showed a fast variation of these parameters (Table 3); pH and $P\text{-}PO_4^{3-}$ increased, whereas nitrogen forms showed great fluctuation (nitrification process) providing a favourable environment for phytoplankton production (Fig. 1e), and consequently that of zooplankton when phytoplankton biomass is not so high to cause growth inhibition (Liady et al. 2015 and references there in). Indeed, the extent of pH preferences for fish is usually 5–7 to 7–9 (Peterson et al. 1989). Our findings were like those obtained by Bokossa et al. (2014a). The high content of suspended solids can be correlated with all inorganic and organic substances contained in a liquid, the total dissolved substances in water and salinity in the mineral environment released from rabbit manures during mineralization in T_4 and T_2. This corroborates the results of Guibaud et al. (2013) on the effect of mineralization in fresh water with waste and with various anthropogenic activities in Morocco (Nechad et al. 2014). The organic fertilizer decomposition is assured by heterotrophic microorganisms which release various minerals while consuming oxygen (Mérigout 2006). The different values of nitrite recommended in fish farming ponds range from 0.5 to 2 mg/L (Dwamd 1994). This tendency which was found in T_1, T_2, and T_3 around the 36th day of the experiment confirms the results obtained by Grunert et al. (2016) during the conversion of nitrogen in the growth of horticultural plants. This decline could be explained by the low phosphorus content in rabbit manures in our experiments. Phosphorus content was important in T_4 and explains that the degradation of organic matter continues under its influence. In fact, phosphorus allows microorganism's longer life time than nitrogen (Durand et al. 1983). The orthophosphate content from T_4 was higher than those obtained by Bokossa et al. (2014a), whose maximum value was 2.80 mg/L. This difference could be explained by the type of organic fertilizer, animal species, and tested diet. The phosphorus richness in T_4 can be a reliable source of mineralization for the development of aquaculture. The nutrient concentrations in the rabbit manure can be used to a good production of microalgae in aquaculture systems, namely, because of their role on microalgae's growth in freshwater (Martin et al. 1985). The high concentrations of K^+, Ca^{2+}, and Mg^{2+} in T_4, T_3, and T_2 proved the presence of released nutrients in water and justify the high conductivity obtained. Suspended solids induced degradation of aquatic ecosystems by reducing light penetration in water, damage the gills of fish, total or partial closure of habitats, and spawning leading depletion oxygen and create a hostile environment for the life of aquatic organisms (Massa 2000; Foster and Charlesworth 1996), but from our results, the low value of suspended solid in T_3 and T_4 treatments is a worthy asset for aquaculture production.

Correlation between physicochemical variables and nutrient dynamics

The use of PCA clarifies the relationships between variables and phenomenon behind these correlations (Fig. 2a). It is used in many water dynamic studies and facilitates aquatic ecosystem studies (Ladhar et al. 2014). PCA showed that the mineralization was related mainly to orthophosphate content and to some extent to ammonium, calcium from which increasing conductivity. These results are different from those obtained by Amadou et al. (2014) in physicochemical and bacteriological analyses of wastewater. The most important effect of the mineralization in our study was characterized by high levels of orthophosphate in T_4 which is a major source of plant nutrients (Fig. 2b). Similar results were observed by Diallo et al. (2014), and highlight the inseparable link between orthophosphates and the growth of plants and even point out its essential role in eutrophication process. The increase in conductivity is correlated with increased nutrient levels (Belghiti et al. 2013; Rodier et al. 2012; Bokossa et al. 2014a). Indeed, T_2 and T_4 released nutrients such as nitrogen, phosphorus, potassium, and calcium, which are the cause of the increase in conductivity. We noticed a nitrogen loss during the mineralization process. It would be necessary to offer to agriculture and fish farmers a contribution on a regular way of use of rabbit manures to fill the gap.

Conclusion

Following the results obtained from the mineralization process of different rabbit manures in fresh water, we can conclude that it can serve as enrichment for fresh water in agro-piscicultural systems. Nutrients released from organic wastes (as rabbit manure) can provide a good yield in such systems at a lower cost compared to chemical fertilizers. This study of enrichment of water by rabbit manure resulting from different diets including classic diet (T_1), improved diet with *I. aquatica* (T_2), improved diet with *E. Guineensis* (T_3), and improved diet with *P.* Maximum (T_4) showed that the mineralization moved towards orthophosphates, calcium, and magnesium. Treatments T_4, T_2, and T_3 had good physicochemical characteristics offering favourable conditions for fish production by the means of algae production (phytoplankton), contrary to the treatment T_1. Moreover, T_4 treatment because of its high phosphorus content offers more optimal conditions for the production of microalgae. Water quality in terms of minerals content varies according to the diets.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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