Vol. 15(2), pp. 323-329, February, 2020
DOI: 10.5897/AJAR2019.14218
Article Number: 3B049C863055
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

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African Journal of Agricultural Research

Full Length Research Paper

Fertilizer management and nutrient use efficiency on rice paddy in integrated system

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Received 31 May, 2019; Accepted 25 November, 2019

Nitrogen budget under integrated production system in fish farming is one of the acceptable practices in maintaining ecological balance and circulation. This result reveals the patterns of pond water and nutrient flows which were strongly influenced by the main fish farming activities resulting to large amount of nitrogen inputs. The main nutrient input sources of nitrogen into the system were found to be pig manure, feed and maggot while outputs were in water, soil, harvested fish and rice; and also in unaccounted forms as a result to discharge. Nutrient composition of rice paddy in integrated production system records 17% N, 19% P and 64% K. The NPK value recorded in integration production system throughout the period of the experiment showed significant difference (p>0.05). There was a positive correlation between nitrogen in rice and rice growth r=0.8373 and 0.7709. The Increase in nutrient is correlated with the increase in the rating of rice growth. The increase in nutrient of unaccounted forms which accumulate in the sediments absorbed by the plant from the soil plays an important role in balance of an aquaculture system. Thus, in order to ensure sustainable productivity there is need to enhance the management of all the nutrient input channels while minimizing the nutrient output through crop intensification.

Key words: Nutrient budget, nutrient input, nutrient output, pond effluent, soil, amendment.

INTRODUCTION

The aquaculture industry faces growing pressure to operate under strict environmental safety standards. These standards lead to the development of integrated agriculture-aquaculture systems, designed to maintain a high biological carrying capacity (Twarowska et al., 1997; Thoman et al., 2001). Water exchange and cost in these systems are minimized through the use of biological, chemical and nutrient efficiency in the pond system. Fish farming has been an important development in recent decades in response to the growing global market demand (Costa-Pierce, 2002). Meeting the demand for fish farming in production systems has developed ranging from extensive to semi-intensive with increasing use of artificial food and high water quality (Crab et al.., 2007). Previous reports on nutrient budget reveal that 90% of nitrogen and phosphorous inputs is in the form of feed,

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whereby the major portion is lost and less being assimilated as biomass. The nitrogen waste such as ammonia and nitrite when produced during culture exceeding its recommended capacity in open waters leads to deterioration of water quality. Nevertheless, crop wastes accumulate in water, as in the case of uneaten food and metabolic wastes that increase as time goes on with the intensification of the cropping system (Lin, 1995). Previous studies show that nutrient balance in an open system for tilapia culture with only 21.4 and 18.8% nitrogen and phosphorus incorporated in the feed are retrieved at the time of harvest; the rest are losses that are downloaded as metabolic contaminants through effluent (Siddiqui and Al-Harbi, 1999). The residual nitrogen produced in the culture system (eg ammonia and nitrites) generally exceeds the assimilative capacity of the system, which impairs water quality creating a toxic environment for tilapia (Avnimelech, 1999; Hargreaves and Kucuk, 2001). The outcome of an integrated agriculture-aquaculture system is based on the balance between production and waste assimilation capacity in the pond environment which results into sustainable scale and gives account for the impact of its waste and growth of culture of aquatic organisms (Martins et al., 2010). The basic steps to establish a balance of nutrient in an integrated system is to evaluate the efficiency of fertilizer use, uneaten feed, crop waste accumulation in water, metabolic waste, water quality in biological and physio-chemical processes (Avnimelech and Kochba, 2009).

Problem associated with integrated system is the nutrient discharges effluent from fish farms which causes rapid eutrophication in ponds and receiving water bodies, along with organic matter accumulated during the growing season, and its impact has been a major environmental concern (Phillips et al.., 1993; Piedrahita, 2003). The approach used to mitigate the impact to the environment through the discharge and disease spread by contaminated water is using water recycling in integrated agriculture-aquaculture systems (Timmons et al., 2002; Piedrahita, 2003) thereby manipulating the environment to improve nutrient efficiency of the farm as a whole (Prein, 2002; Lightfoot et al., 1993). This is perceived as a type of integrated resources management which encourages the increase in production through understanding of chemical and biological processes of the ponds (Boyd, 1986). The pond sub-system should be integrated as much as possible with activities to maximize production while minimizing nutrient discharges.

MATERIALS AND METHODS

The experiment was carried out at the University of Ibadan in the Department of Aquaculture and Fisheries Management, fish farm. The research facilities involved an earthen pond with rice paddy, maggot house and pig sty.

Pond sedimentation was sampled at a depth of 20 cm in two (2) sampling locations A and B in rice paddy. Soil samples were collected initially, weekly monitored and at harvest. The composite sediments samples were air-dried at room temperature; sample was dried at 105°C to a constant weight for the determination of bulk density (Boyd, 1998), then sampled for further chemical analysis: Organic matter (Walkley-Black), total nitrogen (Kjeldahl), available phosphorus (Bray-2) and exchangeable potassium ($BaCl_2$ 0.1 N solution). The data were aggregated to estimate soil nutrients stocks of the Integrated farming systems.

Other parameters of samples were analyzed and recorded to determine nutrient contents in fish feed, maggot, water (ground water, rain water) and pig manure. Representative samples of each material used as a nutrient input to the pond were analyzed.

Pond nutrient budget

The nutrient inputs were separated into on-farm and off-farm sources. The on-farm sources are: pig manure and maggots. The off-farm sources included: fish stocked, commercial fish feed, and nutrients introduced through water recharge before stocking and rainfall into the pond. The nutrient outputs were separated into harvests and losses. The harvests included: fishes, rice yield, rice plant and aquatic plant. The losses included: outflow water (leakage, evaporation), pond effluent, and accumulation in pond sediments.

Nitrogen budget

Input = Output ± Unaccounted

Where Input is: fish feed, maggot, and pig manure and water exchange; Outputs are: soil, pond effluent, and fish; unaccounted: are assumed as taken by rice. The general balance equation was calculated according to the methods of Nhan et al. (2007) and Teichert-Coddington et al. (2000).

WE in + Fert in + Fe in = PE out + S out + F out ± UN

Calculated as described above; WE- –water exchange; Fert - fertilizer (Pig manure); Fe- fish feed; PE- pond effluent; S- soil sediment; F- fish; UN- unaccounted nutrient (rice yield, rice plant).

Statistical analysis

Descriptive statistics was used to present growth performances. Correlation and regression was used to analyse the nutrient budget data. Correlation and regression were used to investigate relationships of fish, rice growth data and water quality data.

RESULTS

Soil characteristics

The nature of soil component was measured before and during the paddy growing period. The composited soil samples in the rice fish field after 16 weeks of culture period showed reduction in the amount of silt and increase in clay content in line with Kajiru et al. (2015) and Frei et al. (2007). In this study, the textual classes of the soil ranged from sandy clay loam to loamy sand.

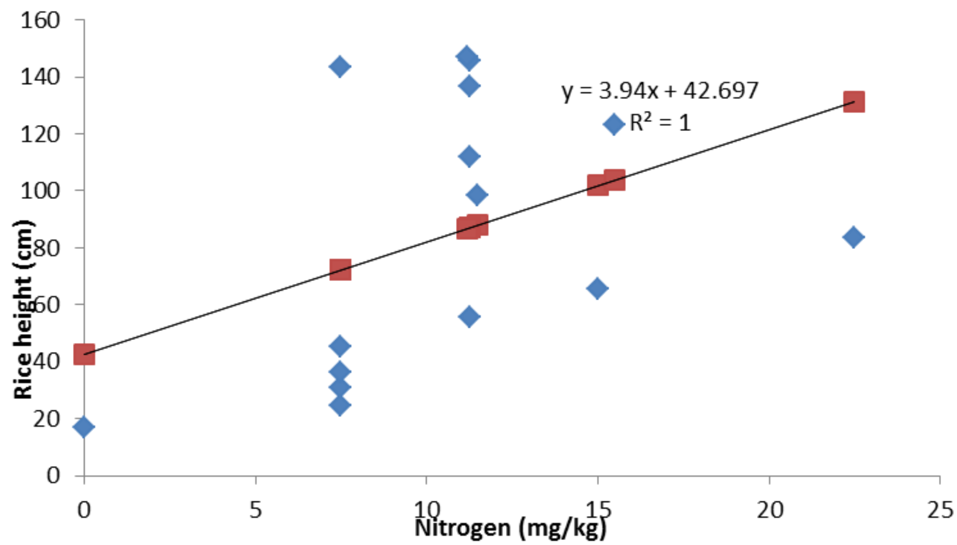

Figure 1. The relationship between rice plant height and nitrogen for sixteen weeks.

Nutrient inputs

Laboratory analysis for nutrients in pig manure indicated that the manure samples contained 0.124% nitrogen, 1.848% phosphorus, 0.685% potassium, 8.040% calcium and 1.610% magnesium. Fish feed nutrient indicated 45% protein, 14% fat, 7 - 8% ash, 2.6 - 2.7% fibre, 1% phosphorus while maggot (supplementary feed) indicated 4.75% protein, 2.5% fat, 0.755% ash and 0.477% fibre.

Nutrient amendment

Mean nitrogen concentration was recorded as 9.89±5.80 mg/kg. The nitrogen concentration in rice paddy before transplant was 12.1 mg/kg followed by a decline in the study period and remained low at 7.5 mg/kg (Figure 1) till six weeks of the rearing as shown in Table 2. Nitrogen concentration increase (22.5 mg/kg) trend in the later part of the study which showed highest concentration level in week nine. Available phosphorus concentration in paddy fluctuated as shown in Table 2 without any definite trend and concentration in rice paddy before transplant was 12.1 mg/kg which showed an increase during the rearing period. The mean phosphorus concentration was recorded as 11.46±5.88 mg/kg. The highest concentration (18.5 mg/kg) was recorded in week six, eight and nine and dropped remarkably at week sixteen (2.3 mg/kg). Potassium concentration in rice paddy before transplant was 31 mg/kg which showed an increase during the rearing period. Mean nitrogen concentration was recorded as 38±21.9 mg/kg. Potassium concentration showed alternate decline and surge throughout the study period. An exponential increase in potassium concentration (80 mg/kg) was observed in paddy from week eight followed by a sharp decline of 17 mg/kg at the end of rearing cycle. Organic carbon concentration was recorded as 134.35±41.57 mg/kg. Over the study period, organic carbon concentration in rice paddy before transplant was 103.05 mg/kg followed by an increase during the rearing cycle. A sharp increase (181.5 mg/kg) was recorded from week nine of the experiment followed by a decline toward the end of the rearing cycle. Organic carbon contents translate to organic matter contents in the soils. The organic matter present in rice paddy was 10.31 mg/kg before transplant and at harvest was 12.69 mg/kg; which showed a steady increase and decline towards the rearing cycle. The rice paddy pH values ranged from 6.4 (slightly moderate acidic) to 7.75 (neutral soil reaction) with a mean pH of 6.77±0.47. The optimum soil pH for rice production ranges from 5.5 to 8.92, from neutral soil to alkaline (Landon, 1991) which can be produced in non-irrigated condition and under flooded condition system. pH values remained within the recommended range all through the rearing cycle. The pH value before planting was 6.45 and at the last planting season, pH was recorded as 6.74. The pH value obtained in this study showed significant difference ($p>0.05$) and it was seen that there was a positive relationship.

DISCUSSION

The soil characteristics presented in Table 1 reveal an increase in clay content. It has being recorded that clay content is suitable for rice production because of their capacities to retain plant nutrient and soil water (moisture). These high clay content restrict the percolation of water through soil, hence encouraging ponding of bundled fields (Kajiru et al., 2015) as well as extends and improves the water use efficiency of the harvested rainwater by the rice plant. This can be due to nutrient

Table 1. Rice paddy soil characteristics samples in integrated culture system.

Parameter (unit)	Before cultivation (initial)	Final
Texture		
Sand (%)	84.2	83.6
Silt (%)	12.4	7.0
Clay (%)	3.4	9.4
Texture	Loam	Loam
Organic carbon (mg/kg)	1.03±0.1	0.80±0.7
Organic matter (mg/kg)	1.77±0.2	1.37±0.2
Total nitrogen (mg/kg)	12.2±3.7	11.2±14.1
Available phosphate (mg/kg)	9.52±14	2.39±0.3
Potassium (mg/kg)	31±42	17±28.3
pH (mg/l)	6.5±0.1	6.7±0.2

Table 2. Mean value of rice paddy soil characteristics and nutrients in integrated culture system.

Week	Nitrogen	Phosphorus	Potassium	pH
Initial	12.2±3.7	9.52±1.4	31±42	6.5±0.1
3	7.5±0	12.5±0	30±0	7.5±0
4	7.5±0	12.5±0	30±0	6.75±0
5	7.5±0	12.5±0	110±70.7	6.75±0
6	7.5±0	37.5±17.7	30±0	6.75±0
7	22.5±10.6	12.5±0	80±0	6.75±0
8	15±0	37.5±17.7	80±0	7±0
9	45±21.2	37.5±17.7	80±0	*6.25*±0
10	11.5±7.0	10.85±0.5	37.5±4.5	6.3±0.1
11	22.5±10.6	12.5±0	80±0	**7**±0
12	15.5±7.0	13.8±0.4	48.5±0.7	6.8±0.1
13	22.5±10.6	12.5±0	80±0	6.75±0
14	7.5±0	12.5±0	30±0	7±0
15	22.5±10.6	12.5±0	30±0	6.75±0
16	11.2±14.1	2.39±0.3	17±0.7	6.7±0.2

accumulation from ammonia present in water. The nitrogen value recorded in integration production system throughout the period of the experiment showed significant difference ($p>0.05$) and it was seen that there was a strong positive relationship.

On the whole, the mean soil nutrients recorded as shown in Table 2 during the study were within the range reported by Nwilene et al. (2008) for optimum growth and rice production. Phosphorus obtained in this study showed no significant difference ($p<0.05$) and it was seen that there was a positive relationship. Since rice plant is a low demanding crop, the observed plant available phosphorus value would satisfy the phosphate demand by the rice. In addition, the availability of phosphorus in rice paddy is a function of soil pH (Inusa et al., 2013; Kajiru et al., 2015). Hence, the availability of the soil phosphorus may be negatively affected by the high pH values of the soils. The potassium recorded in integrated production system through the period of experimental study showed significant difference ($p>0.05$). On the whole, the mean soil nutrients recorded in this study were within the range reported by Nwilene et al. (2008) for optimum growth and rice production. Under tropical and subtropical conditions, requirement for N, P_2O_2 and K_2O are reported to be 80, 30 and 30 kg/ha respectively. This variation in organic matter in soil influence physical, chemical and biological properties of soil such as soil texture, water retention, nutrient content and retention and microbial activities in soil (Frei et al., 2007). Application of livestock manure increases soil organic matter content, leading to improved water infiltration and water holding capacity, as well as an increased cation exchange capacity. Rasowo et al. (2008) reported that manure and urine raise the pH level and accelerate the decomposition of organic matter and activity. It is reported that cultivation of rice is even possible with the

Table 3. Total Nitrogen budget used in the nutrient input and output calculations.

Week	Input					Output				Unaccounted
	Water	Pig Manure	Feed	Maggot	Total	Water	Soil	Fish	Total	
0 (g/kg)	2.75	1.24	91.20	47.40	142.59	2.99	1.22	45.60	49.81	88.57
%	1.96	0.87	63.78	33.57	100.00	2.10	0.86	32.00	34.96	65.04
4 (g/kg)	2.99	0	72.00	47.40	122.39	2.99	0.75	36.00	39.74	78.95
%	2.50	0	58.80	38.70	100.00	2.44	0.61	32.00	35.05	61.90
7 (g/kg)	0.01	0	72.00	47.40	119.41	3.97	1.15	43.20	48.32	65.97
%	0.01	0	60.30	39.70	100.00	3.32	0.96	36.00	40.28	55.44
10 (g/kg)	0.02	0	72.00	47.40	100.00	0.02	1.15	28.00	29.16	89.10
%	0.01	0	60.30	39.70	100.00	0.01	0.96	31.00	30.97	68.06
13 (g/kg)	0.02	0	72.00	47.40	119.42	0.02	1.15	29.00	30.17	80.08
%	0.01	0	60.30	39.70	100.00	0.01	0.96	24.00	25.16	73.68
16 (g/kg)	0.02	0	72.00	47.40	119.42	0.01	1.12	29.00	30.13	88.15
%	0.01	0	60.30	39.70	100.00	0.01	0.94	24.00	24.95	74.10

Table 4. Nutrient budget for sixteen weeks in the fish cum rice and pig Integrated production system.

Weeks	Unaccounted (g/kg)	Mean Rice Height (cm)
Initial	88.57	10.12±2.12
4	78.95	30.67±3.12
7	65.97	55.51±5.53
10	89.10	98.33±9.68
13	80.08	136.51±10.40
16	88.15	146.97±11.65

pH up to 9.0 but high pH values of the soil could negatively influence the availability of the micronutrient as well as phosphorus (Kajiru et al., 2015).

Nitrogen budget in integrated production system over the study period revealed that fish feed as the major input of nitrogen is shown in Table 3. Nitrogen in form of feed ranged from 58.80 to 63.78% and maggot input through feed ranged from 33.57 to 39.70% of the total inputs; the result is in agreement with Nhan et al. (2007) and Prein (2002). It has being reported previously that the predominant inputs of nitrogen in water exchange unit are feed, which accounted for 82-95% nitrogen of total inputs. Feeds nitrogen gain by ponds occurred primarily from feed 36% and fertilizer at 1.1% in the present study; also, contribution of feed to the total nutrient inputs is in the same range as reported. In addition, nitrogen through feed was significantly higher throughout the study period. Nutrient budget showed that some portions of the nutrient were deposited in soil followed by nutrient contained in water at harvest, and relatively large fractions were unaccounted as observed in Table 3. Percentage nitrogen accumulates into the soil and water (effluent) ranged from 0.61 to 0.96% and 0.01 to 3.97%. In addition, nutrient budget revealed that during the rearing cycle, large percent of the nitrogen went unaccounted for. Unaccounted nitrogen ranged from 95.75 to 99.05% of the total inputs. Moreover, further accounting of the nutrient budget revealed that rearing 1 kg fish resulted into 72 g N loss throughout the study period. Nutrient budget showed in Table 3 that the total of inputs were incorporated into harvested fish and rice yield; the remainder in the system as uneaten feed, excreted material went to support high level of phytoplankton, heterotrophic activity and rice growth.

These unaccounted forms were deposited in fish and rice growth in line with Rukera et al. (2011) and Inusah et al. (2013) as shown in Table 4. It was reported that the major output of nutrient in water exchange ponds were in discharge water. This experiment showed in Table 3 that in an integrated production system losses of nutrient are through sediment and is higher than water borne loss. Integrated production system unit excess of nutrient input, which especially originated from eaten feed, keep accumulating in the system and in turn may support growth of natural food organism, ultimately fish growth and increase in the yield of rice. Furthermore, in this experiment it was observed that the increased unaccounted nutrient was absorbed by the plant from the soil. Rukera et al. (2011) mentioned that the sediment which accumulates the nutrient plays an important role in balance of an aquaculture system; it can act as a buffer in water nutrient concentration and helps in minimizing loss from the system. However, from the nutrient budget data, it is apparent that larger percentage of the nutrient inputs went unaccounted in the integrated production unit. The nitrogen content of the nutrient budget at the end of the experiment provides insight into the physical characteristics of potential effluent waste and magnitude of denitrification.

Boyd and Tucker (1998) mentioned that the most probable loss of nitrogen is by ammonia gas volatilization which is further enhanced by vigorous aeration and high pH and nitrogen fixation by blue-green algae. In this study, some of the potential sources of nitrogen were not accounted for such as inorganic nitrogen inputs through precipitation which was considered insignificant and nitrogen fixation by blue-green algae. In accounting for the nutrient budget, it revealed that rearing 1 kg fish resulted into 70 g (58%) of nitrogen used up in integrated production system.

The correlation coefficient was computed to assess the relationship between rice growth, fish growth and ammonia. There was a positive correlation between nitrogen in rice and rice growth r=0.8373 and 0.7709 as shown in Figure 1, leading to a strong positive correlation between the two variables. Increase in nutrient correlated with increase in the rating of rice growth. Meanwhile, a negative correlation between nitrogen in fish and fish growth r=-0.8367 leads to a strong negative correlation between the two variables.

Conclusion

Thus, it is worth pointing out that the use of nutrient rich water such as nitrogen, phosphorus and total dissolved solids to irrigate alleviates a potential problem of pollution. Therefore, maintaining soil structure and fertility through its use, as well as the risk of soil degradation had been reduced. The study provides management practice in integrated production system for nutrient budget; this system unit nutrient input originated from eaten feed which accumulates and supports growth of natural food organism. The increase in unaccounted nutrient which accumulates in the sediments was absorbed by the plant from the soil, plays an important role in balance of an aquaculture system, acts as a buffer in water nutrient concentration and helps in minimizing loss from the system. Thus, in order to ensure sustainable productivity there is need to enhance the management of all the nutrient input channels while minimizing the nutrient output through crop intensification. Farmers need to better regulate water and nutrient flows between the pond and the other IAA-farm components to maximize the productivity and profitability while minimizing nutrient discharges of the whole farm.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

ACKNOWLEDGEMENT

The author greatly acknowledged CORAF/WECARD Research Project team who through Poverty Eradication and Grassroots Empowerment through Sustainable Integrated Aquaculture Development: supported this adaptive research at the Department of Aquaculture and Fisheries Management, University of Ibadan in conjunction with West and Central African Council for Aquaculture Research and Development (WECARD).

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