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Full Length Research Paper

Water balance and water use efficiency in fish-rice integrated agriculture-aquaculture

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Aquaculture is dependent on water supply. This result reveals pond consumptive water use and water balance in fish-rice integrated system. Water balance variables were measured daily from meteorological station and computed following the standard procedure. Total water input and output in fish culture were 318.0923 and 26.631 m^3, respectively; while in rice cultivation, they were 79.9722 and 6.5732 m^3. They were measured on a daily basis with the overall presented on weekly records; the average water balance for rice paddy and fish culture was 75.1563 and 297.4433 m^3, respectively. Fish growth showed the amount of water used for production (kg/m^3) in integrated pond, right from fingerlings to table size fish. This shows the required amount of water used for productivity at different weeks. Rice growth showed the amount of water required for paddy in an integrated pond throughout the productive period. Water use efficiency based on rice growth showed increase weekly due to use of aquaculture effluent without fertilizer treatment. The results showed that water channels could be strongly influenced by weather and climate pattern affecting farming activities. Hence, IAA is an acceptable practice which ensures multiple and conjunctive use of scare water resources for higher productive farm outputs and future strategies for enhancing water productivity.

Key words: Water use efficiency, water balance, rice plant, fish growth, rice paddy.

INTRODUCTION

Water is very essential for agricultural planting; therefore, the success of farming will also be determined by how much we can expect from the availability of water for crops and animals (Prein, 2002). Aquaculture is dependent upon supply of water. Global freshwater withdrawal has increased nearly seven-fold in the past century with agriculture being the largest global consumer of freshwater. The agricultural sector is a major freshwater consumer and around 70% of the world's freshwater withdrawal is for irrigation (Gordon et al., 2010). With a growing population and economic development, coupled with changing diet preferences,

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water withdrawals and demand for freshwater have been increasing continuously and it is expected to increase in the coming decades. UNEP (2007) anticipated that water withdrawal will increase by 50% in developing countries by 2025 and 18% in developed countries. The World Water Development Report predicted increase by 19% to reach 8515 km^3 per year by 2025 of global water consumption of agriculture. Currently, agricultural sector accounts for about 85% of global blue water consumption. The increase in the consumption of animal products is likely to put further pressure on the world's freshwater resources.

Freshwater is a renewable but finite and therefore scarce resource. Its availability and quality show enormous temporal and spatial variations. Freshwater systems are sensitive to human influence and environmental degradation and algae are good indicators of water quality and environmental changes due to external sources (Bubu-Davies et al, 2022). An increasing population coupled with continued socio-economic development puts an increasing pressure on the world's freshwater resources. In many parts of the world, there are signs that water use exceeds a sustainable level. The reported incidents of groundwater depletion, rivers running dry and worsening pollution levels are signs of the growing water problem (Vörösmarty et al., 2010). Green water known as rain water is productively used and evaporates from vegetation canopies. Rainwater harvesting is preferable because of the potentiality of increased production, early recovery cost, low construction cost, high benefit-cost ratio, and being easy to use and maintain (Domènech et al., 2012). Research demonstrated that potential rainwater harvesting and its impact on farming system development and performance is a known technique used for better management options with increased crop production. Blue water refers to aquifers withdrawn for irrigation, of which about 60% of all food is produced from rain-fed agriculture. According to Hoff et al. (2010), the global green water consumption for crop production is about four to five times larger than blue water consumption. It has also been recognized that green water sustains all terrestrial non-agricultural activities. Thus, grey water footprint expressed as water pollution in terms of water volume polluted does not only pose a threat to environmental sustainability and public health but can also increase the competition for freshwater resources together with other factors of global water security and river biodiversity (Vörösmarty et al., 2010).

Water balance is used to estimate pond-water availability for fish culture based on prevailing climatic and hydrological conditions. It is therefore a key determinant of the potential for freshwater pond aquaculture. Techniques commonly used in estimating pond-water availability are based on water balance accounting between net gains from inflow versus net losses from outflows (Kam and Hoanh, 2019). This involves water gain from rainfall, percolation and lateral seepage, surface water runoff from immediate surroundings of the pond and loss from pond-water through evaporation. Improving water use efficiency is a critical response to growing water scarcity, including the need to have enough water to sustain ecosystems and to meet the growing demands. According to Sharma and Sharma (2007), increasing water productivity and improvement of agricultural water productivity are appropriate in order to meet the rising demand for food and changing diet patterns, increasingly urbanized population; water pressures from agriculture to industries and ensuring the availability of water for environmental uses and climate change adaptation. Targeting high water productivity can reduce cost of cultivation of crops and lower energy requirements for water withdrawal. Water productivity measures the ability of agricultural systems to convert water into food.

The farming system is facing water crisis due to excessive groundwater withdrawal and climate change. Therefore, the policy on water management needs to be more efficient and to build resilience for coping with climate related uncertainties. These involve efficient management of all component of water cycle for enhancing productivity to meet with the current and future food security. Future scenario underscores the fact that in the future food needs to be met with more efficient use of water resources for providing food and livelihood for the increasing world population. The objective of this study is to evaluate water budget for culture of fish-rice integrated aquaculture agriculture. This estimates prevailing climatic, hydrological conditions and sources of water in improving water management and food security.

MATERIALS AND METHODS

The experiment was conducted in the Department of Aquaculture and Fisheries Management, University of Ibadan. This was carried out for 16 weeks which occurred during the rainy season from May-August. The weather station is situated at 7° 26' 47"N and 3°56'37"E, at an elevation of 213 m above sea level; it has an average temperature of 25.76°C and relative humidity of 82.40%.

The fish rice culture field had an area of 227.5 m^2; fish trench and elevated rice paddy measured 178 and 49.5 m^2, respectively with an elevated height of 0.4 m. Earthen pond was stocked with 900 *Clarias gariepinus* fingerlings with a mean size 2.66±0.2 cm. Fish were fed commercial pelleted feed (45% crude protein) at 5% body weight daily at early stage, with supplementary feed (maggot). Water quality parameters were tested bi-weekly in the morning. Water temperature was measured using thermometer, dissolved oxygen (DO), pH, ammonia (NH_3), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N). Hardness and alkalinity were determined using NT LABS PONDLAB 200 test kit. Culture water was sampled and analysed in line with standard methods APHA (1995). Total final weight of the fish was determined using weight scale.

Elevated paddy was surrounded by fish trench known as rice paddy. Rice paddy was tilled and seedlings were transferred from nursery beds as shown in Plate 1. *Oryza sativa* (FARO 49) rice seeds obtained from National Cereal Research Institute, Ibadan were planted in 30 rows (10 cm × 10 cm). At the rice paddy,

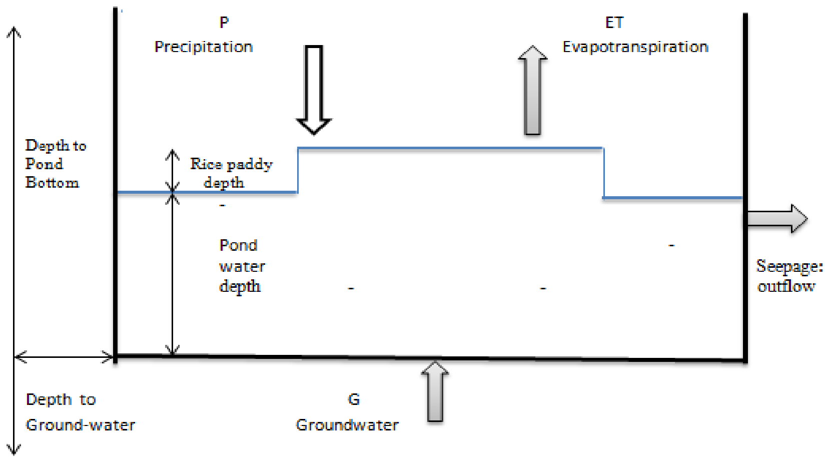

Figure 1. The water balance component.
Source: Author

Plate 1. The Integrated rice-fish culture field indicating (dark arrows) the graduated meters rulers water depth monitoring**.**
Source: Integrated farm, University of Ibadan

minimum water levels were maintained during vegetative period as shown in Plate 2. Insects were controlled through biological method. Plant growth was assessed by morphometric measurement and descriptors weekly after planting on rice paddy according to the Standard Evaluation System for rice (IRRI, 2002).

Water balance was used to estimate the quantity of water input and output in the integrated pond using climatic and hydrological parameters. Water was added daily through groundwater and precipitation (rain), while water loss was mainly due to evapotranspiration, seepage, deep percolation, fish biomass and discharge. Total water input and output in fish rice culture were measured on daily basis with an overall water balance presented on weekly records.

The basic expression of water balance is input-output, accounting for change in water stored in the system. According to Peter (2013), a general equation for water balance is:

$$\Delta S = Q\text{ in} - Q\text{ out}$$

where Qin (total basin inputs) includes precipitation, groundwater inflow and run off; Qout (total basin outputs) includes evapotranspiration, surface and groundwater; ΔS is change in storage. At the field scale, it is considered as:

$$\Delta S = P + G + Q - Et + SWO$$

where P=rainfall, G=groundwater inflow, Q=run off, Et=evapotranspiration, SWO=surface water outflow, and ΔS = changes in storage.

Water balance was computed in two phases during this study:

Rice Paddy water balance: $\Delta S = P + G - Et$
Fish culture trench water balance; $\Delta S = P + G - Et$

The change in storage is the volume of water that shows the difference between the total estimated water inputs from total estimated water outputs (Figure 1). Pond water balance was calculated from water exchange volumes, evaporation, and precipitation for the study periods. Daily precipitation rates were calculated from precipitation distribution in the form of rain that

Plate 2. A view of fish culture with rice plant on paddy in integrated pond.
Source: Integrated farm, University of Ibadan

Table 1. Water balance of rice paddy in Fish cum rice and pig integrated production system.

Week	P (m^3)	G (m^3)	P+G(m^3)	Et (m^3)	∆s (m^3)
1	1.2177	9.4347	10.6524	0.4198	9.8128
2	1.9503	7.722	9.6723	0.8776	7.9963
3	2.3562	11.3652	13.7214	0.4445	12.8324
4	1.8117	8.3358	10.1475	0.5301	9.3016
5	1.0593	5.3163	6.3756	0.4267	5.6078
6	2.7621	9.2961	12.0582	0.4574	11.1434
7	0.2475	2.6532	2.9007	0.3698	2.1928
8	1.1088	1.485	2.5938	0.3544	2.0553
9	2.1780	1.8018	3.9798	0.4495	3.1977
10	0.1683	1.3365	1.5048	0.3816	0.9297
11	0.1782	1.9503	2.1285	0.5346	1.2489
12	0.8019	0.12375	0.9257	0.3812	0.438
13	0.0693	0.84645	0.9157	0.3599	0.3935
14	0.3564	0.99	1.3464	0.3178	0.8197
15	0.3168	0.7326	1.0494	0.2683	0.6133

P-Precipitation; G-groundwater; Et-evaporation; ∆s-change
Source: Integrated farm, University of Ibadan

makes up the primary supply of water to the surface. The precipitation distribution was measured with a computerized automated weather station instrument. Groundwater inflow adds water through aquifers by recharging of water table. Daily inflows calculated and estimates were developed from the daily water stored value based on the numbers of days in each month.

Evapotranspiration combined process by which water evaporates from the fish trench and rice paddy as a result of solar radiation. Evaporation from surface waters is estimated based on the area of surface water in the study area. The amount of water returned to the atmosphere from plants, soil and trench through evaporation and vegetation transpiration was calculated with the use of automated weather station instrument. The computed records of meteorological variables related to water availability were obtained from University of Ibadan weather station (geography meteorological station). Monitoring of pond water volume was measured daily; a staff gauge (two graduated meter rule) was installed and fixed at opposite ends of the fish trench.

Statistical analysis

Statistical analysis was performed using SPSS statistical software. Descriptive statistics was used to present growth performances. Correlation and regression were used to investigate the relationships of fish, rice growth data and water quality data.

RESULTS

The weekly water balance reveals (Table 1) groundwater

Table 2. Water balance of Fish trench in fish cum rice and pig integrated production system.

Weeks	P (m^3)	G (m^3)	P+G(m^3)	Et (m^3)	∆s
1	6.9776	4.4500	11.4276	2.26	9.1676
2	2.8836	42.6132	45.4968	2.11	43.3868
3	5.7672	24.7776	30.5448	2.65	27.8948
4	9.5052	44.8560	54.3612	1.7925	52.5687
5	8.2236	35.3152	43.5388	1.8476	41.6912
6	1.5308	12.7092	14.2400	1.7195	12.5205
7	11.2852	15.6640	26.9492	1.3706	25.5786
8	1.7800	29.3700	31.1500	1.5949	29.5551
9	0.1068	3.4888	3.5956	1.2869	2.3087
10	11.7124	12.5668	24.2792	1.4258	22.8534
11	0.6408	5.2332	5.8740	1.4489	4.4251
12	0.6408	3.5600	4.2008	1.9473	2.2535
13	0.0000	5.3400	5.3400	1.3955	3.9445
14	2.9904	1.7088	4.6992	1.3528	3.3464
15	1.2816	3.5600	4.8416	1.2887	3.5529
16	1.2816	4.2720	5.5536	1.14	4.4136

P-Precipitation; G-groundwater; Et-evaporation; ∆s-change.
Source: Integrated farm, University of Ibadan

Table 3. Water use efficiency of fish trench in fish cum rice and pig integrated production system.

Week	WVT (m^3)	BW (kg)	P (kg/m^3)
2	119.95	9.77	0.08
4	119.65	22.61	0.19
6	119.83	41.86	0.35
8	139.39	75.65	0.54
10	159.49	147.97	0.98
12	169.45	191.52	1.13
14	173.64	259.72	1.50
16	175.7	312.08	1.78

WVT- Water volume trench; BW- body weight; P- production.
Source: Integrated farm, University of Ibadan

as the highest input source and its peak was observed at the 3rd week. This is followed by increase in the 1st, 4th and 6th weeks which corresponded with an increase in precipitation and fluctuated with a decrease. Evaporation was observed as the highest in the 2nd week.

The water balance presented in Table 2 reveals an increase in groundwater at week 2 with a continuous rise at 4th week; while the lowest range was observed in week 14. Precipitation increased and fluctuated with its peak at the 10th week; there was lowest range at week 13 with no significant rainfall. Evaporation increased at first week and fluctuated with a decrease towards the end of the study.

Water exchange observed in Table 3 shows the consumptive water used for production of catfish at different stages, from fingerlings to table size in integrated pond. The results indicate that the body weight of fish requires certain amount of water for production at different stage. At the 2nd week, the body weight of 1000 fingerlings (9.77 kg) has water requirement of 119.95 m^3 for the production of 0.08 kg/m^3. However, the consumptive water used in the 2nd, 4th and 6th weeks remained at a close range. This was followed by an increase in the body weight, leading to high production rate. Water use efficiency based on fish body weight (kg) was seen in production (kg/m^3).

Table 4 shows the water requirements for rice growth in integrated pond. Thus, the results indicate that cubic meter of planted area-rice requires low amount of water between the 2nd, 4th and 6th weeks. However, between 8 to 16th weeks, water requirement increased (17.98 m^3) . This is followed by rice growth at 60 cm with 5 leaves present; while reduction of water was observed towards the end of the production cycle at week 16 with 2.19 to 21.30 m^3 water consumed. Water use efficiency based on rice height and number of leaves increase weekly due to aquaculture effluent.

The results indicate that rice and fish were cultivated and reared during the wet/rainy season. Table 5 shows the values of consumptive water use for rice crop cultivation and catfish production. The total numbers at initial and final stage were observed in cultivation of rice; height, leaves, strand, water use efficiency and rearing of fish; and body weight, number, water use efficiency data are shown.

Table 4. Water quantity and rice growth for rice paddy in integrated production system.

Week	WVP (m^3)	RH (cm)	RL (n)
2	7.29	13	2
4	9.52	27	3
6	8.33	41	4
8	17.98	60	5
10	21.47	91	6
12	22.74	117	7
14	23.19	139	8
16	21.30	145	10

WVP- Water volume paddy; RH- rice height; RL- rice leaves
Source: Integrated farm, University of Ibadan

Table 5. Range production indices of rice and fish growth in integrated system.

Production	Rice		Production	Fish	
	Initial	Final		Initial	Final
Range height (cm)	8.0 -12.24	135.33-158.63	Range weight (g)	2.46 - 2.86	382.9- 449.3
Range leaves (n)	2 -.3	9 - 10	Fishes (g)	900	750
Rice strand	1058	1034	Consumption (m^3)	119.95	176.3
Consumption (m^3)	7.29	27.46			

Source: Integrated farm, University of Ibadan

Rice cultivated on an elevated paddy is surrounded by fish trench in fish cum rice integrated system. This shows a concurrent multiple uses of water and nutrient linkage in integrated agriculture aquaculture (IAA) (Table 6 and 7).

DISCUSSION

Water balance estimates the quantity of water entering and exiting through various pathways. In this study, weekly fluctuations of freshwater input correspond with the change in storage (Figures 2 and 3). This is in line with Hoekstra et al (2012), who reported that consumptive water used varies according to the climate characteristics of a given region mainly precipitation. According to Taylor et al. (2013), water will respond to climate change and is expected to affect the hydrological cycle. Water input in rice paddy that amounted to the increase in pond water corresponded to the rainfall pattern. According to Nhan et al. (2006), the water input from rainfall almost compensated for the loss from evaporation, and filling and drained water volumes were comparable. IAA-pond farming in the Mekong delta practiced water conservation measures in maximizing storage volume for rainfall into ponds and minimizing excessive water exchange. Groundwater observed the highest thus contributed to large percentage of water input in IAA-ponds during rainy season. Kundzewicz et al. (2007) demonstrate that groundwater levels correlate more strongly with precipitation than other variables. However, this indicates the existence of highly permeable channels from land surface to water table (Hunt et al., 2008). Evapotranspiration demonstrates an increase with average humidity recorded and temperature at 27.65°C. The amount of water in the atmosphere increases through evapotranspiration, but decreases again through precipitation.

As demonstrated in Table 2, fish trench has a cumulative consumptive water of 297.4433 m^3 and output at 26.6341 m^3. Consumptive water use emphasis on water use efficiency in improved agricultural water management has been on the increase while increasing water productivity in producing more with relatively less water (Sharma et al., 2010). Towards the end of the production, reduction in water input leads to reducing freshwater consumption (4.8309) in fish trench, thus correlates toward the end of rainy season. The results observed show a distinct response with the groundwater. Woldeamlak et al. (2007) showed that under climate scenarios, wet-climate with the predicted increases result in rising groundwater levels and precipitation while under dry-climate scenarios decrease resulting in groundwater level declines. This is known to have adverse effects on local aquatic life in local wetlands and riverine

Table 6. Climatic variables in rice paddy in IAA.

Week	Climatic data		Water variables		
	T (°C)	R H (%)	P (m³)	G (m³)	Et (m³)
1	27.825	80.512	1.2177	9.4347	0.4198
2	27.654	81.643	1.9503	7.722	0.8776
3	27.058	82.298	2.3562	11.3652	0.4445
4	26.235	81.823	1.8117	8.3358	0.5301
5	26.074	82.262	1.0593	5.3163	0.4267
6	26.191	83.089	2.7621	9.2961	0.4574
7	25.138	82.006	0.2475	2.6532	0.3698
8	25.218	82.474	1.1088	1.485	0.3544
9	25.646	80.077	2.1780	1.8018	0.4495
10	25.117	81.030	0.1683	1.3365	0.3816
11	25.210	82.756	0.1782	1.9503	0.5346
12	24.345	82.980	0.8019	0.12375	0.3812
13	24.899	83.800	0.0693	0.84645	0.3599
14	25.028	83.768	0.3564	0.99	0.3178
15	25.029	83.440	0.3168	0.7326	0.2683

T-Temperature; relative humidity; P-precipitation; G-groundwater; Et-evapotranspiration.
Source: Integrated farm, University of Ibadan

Table 7. Climatic data in IAA throughout the study period.

Week	Data		Variable		
	T (°C)	R H (%)	SR mj/m^2/day	P (m³)	Et (m³)
1	27.825	80.512	9.448	6.9776	2.26
2	27.654	81.643	8.651	2.8836	2.11
3	27.058	82.298	12.390	5.7672	2.65
4	26.235	81.823	7.461	9.5052	1.7925
5	26.074	82.262	7.689	8.2236	1.8476
6	26.191	83.089	7.116	1.5308	1.7195
7	25.138	82.006	7.028	11.2852	1.3706
8	25.218	82.474	6.633	1.7800	1.5949
9	25.646	80.077	5.244	0.1068	1.2869
10	25.117	81.030	5.806	11.7124	1.4258
11	25.210	82.756	7.071	0.6408	1.4489
12	24.345	82.980	8.138	0.6408	1.9473
13	24.899	83.800	5.899	0.0000	1.3955
14	25.028	83.768	5.573	2.9904	1.3528
15	25.029	83.440	5.309	1.2816	1.2887
16	25.102	82.545	6.734	1.2816	1.1400

T-Temperature; relative humidity; P-precipitation; SR-solar radiation; Et-evapotranspiration.
Source: Integrated farm, University of Ibadan

ecosystems that rely on groundwater discharge to support base flow. As reported, soil water reserves naturally increase according to rainfall and ground water, while regions experience water deficits towards the end of the rainy season. Rice itself is a water consuming crop and addition of fish still increased the water requirement. Channabasavanna and Biradar (2007) reported that integrated farming system consumed 36% higher water than the conventional system of rice-rice; but the water use efficiency was 71% higher in integrated than conventional system. Jayanthi et al. (2000) indicated that integrated farming requires less water per unit of

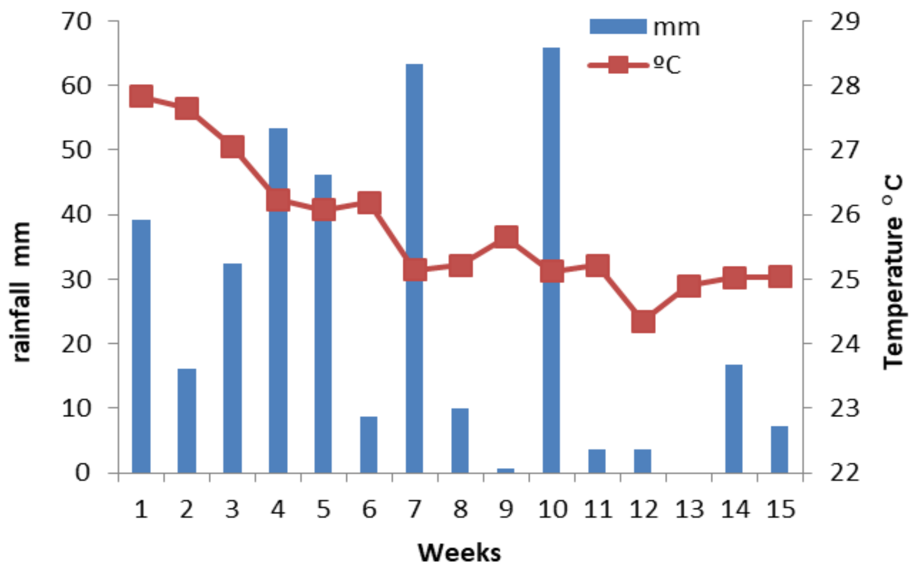

Figure 2. Weekly profile of climatic distribution of Rainfall (mm) and Temperature (°C).
Source: Integrated farm, University of Ibadan

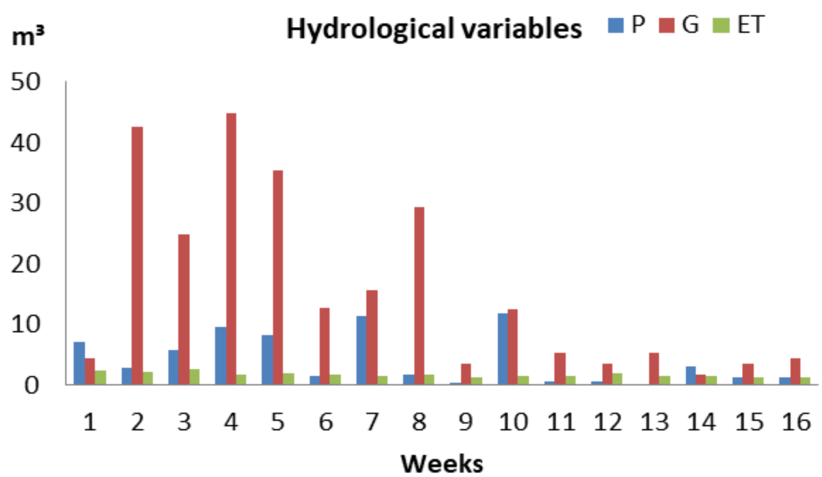

Figure 3. Weekly profiles of water balance parameters.
Source: Integrated farm, University of Ibadan

production than mono-cropping systems. In line with Abdul-Rahman et al. (2011), water use efficiency of integrated treatment is greater than WUE of non-integrated treatments. This improved farm productivity and increased water productivity, thereby increased farm income without additional consumptive use of water through adoption of IAA technology.

Fish are a non-consumptive user of water, and while they can degrade water they do not use it up. If cleaned, the same water can be returned and reused by the fish. The estimated water requirement for producing fishes at 1.78 kg/m^3 was 175.7 m^3 at 312.08 kg. Abdul-Rahman et al. (2011) demonstrated IAA increases water value index, with reduced amount of fertilizers. This is because the water is enriched with aquaculture-generated metabolites. Just like Hopkins, this indicates that integrating tilapia culture with agricultural crops would improve the economic viability of crops by spreading the usefulness of the water systems.

Water availability, water use and nutrient supply to plants are closely interacting factors that influence plant growth and yield production. Rice growth and consumptive water use showed a geometric growth in production cycle. This is in accordance with Sharm et al. (2017) who reported that aquaculture effluents significantly increased yields. Akinbile and Sangodoyin

(2011) showed Malaysia is characterized by a humid tropical climate with average daily temperatures and humidity, which increase rice yield per unit. IAA farms in Malawi increased water productivity substantially, improved total farm production, and increased farm income without additional consumptive water use. Research has proved that nitrogen in fish effluent supplies nutrient requirements for maize growth as evident in the improved yield and WUE of maize fertilized with fish effluent only. Evapotranspiration and transpiration water use efficiency can be increased by raising soil nutrient levels, thus promoting crop growth, increasing transpiration and evapotranspiration water use efficiency. Abraham et al, (2020), reported that Aquaculture effluent rich in nitrogen nutrients acts as an inorganic fertilizer for rice growth, and improves yield and water use efficiency. Evapotranspiration and transpiration water use efficiency can be increased by raising soil nutrient levels, thus promoting crop growth and increasing transpiration thus increasing evapotranspiration water use efficiency.

The available water for production, however, is becoming increasingly scarce due to decreasing resources and quality and increased competition from non-agricultural water users. For food security, it is essential to produce more rice with less water. Abraham et al, (2019), showed Integrated agriculture-aquaculture increases yields thereby establishing the relationships between pond management practices and nutrient accumulation in an eco-friendly environment through strengthening nutrient recycling and enhancing farm outputs for consumption all year round. Water resource management is essential for growing crops in all year round, especially where fish and rice have two production cycles in a year. There is clear need for water harvesting strategies to prolong the duration for fish rice culture. This was demonstrated in Bangladesh in which rainfall was highest; and groundwater table was high reaching the soil surface in rainy season and dropping during the dry season.

Conclusion

Excess water in rainy season and scarcity in the dry season create a situation of water insecurity in the areas of farming sectors. Water use efficiency and farm productivity will need to improve consumptive use of water through adoption of IAA technology. One way of achieving this, is to provide policy and strategy in water resources management, especially in drought-prone areas while maintaining healthy environment and ecological balance. In the present work, IAA system was used as water scale assessment for water use efficiency of fish-rice culture in water balance through various water inlet and outlet channels. This offers an excellent opportunity to make more efficient use of water resources-freshwater consumption in maintaining water quality and fish health. There is a need to find new ways to increase water efficiency by improving biological, economic and environmental output per unit of water used in both irrigated and rain-fed agricultural systems to sustain farm productivity, soil and water quality, and improve livelihood of farmers. Nevertheless, there tends to be variations due to climate and geographical condition that are particular to different regions. There is, therefore, a need to acquire a broader knowledge and a better understanding of the diverse processes affecting water resource management contributing to crop and fish production as well as other goods and services generated by aquatic ecosystems. However, with the increased demand of agriculture-aquaculture, with rising population and increased demand for food, it is essential to respond to water resource management. Hence, water resource management is an essential tool for water resource planning in satisfying the increasing demand.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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