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Water Use in Carp Polyculture: Effects on Rearing Environment and Water Productivity

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This study was carried out in farmers' fields to quantify the total and consumptive water use (CWU) in carp polyculture under different water management protocols. Treatment-wise estimated total crop water requirement ha^{-1} (culture duration-180d) was 3.69, 4.62 and 3.9 ha-m, while the computed consumptive water use index (m^3 kg^{-1} biomass) was 6.62, 9.31 and 7.08, in T_1 (no water exchange), T_2 (10% water exchange on monthly basis) and T_3 (10% water exchange depending on the water quality variables), respectively. Water use in ponds usually varies with the intensity of production, frequency and amount of water exchange employed. Higher the amount of water exchange, higher is the total water use (TWU) as in case of T_2. Various hydro-biological parameters prevailing in the different treatments were within the optimum ranges and did not fluctuate drastically. This was probably due to the similar levels of inputs in all the treatments in the form of organic manure, inorganic fertilizer and periodic liming. The regulated water exchange in T_3, showed improved water quality and crop performance ($P<0.05$) over the zero water exchange, T_1. Evaporation loss contributed significantly to CWU (2.9-3.1 m^3 water kg^{-1} production) followed by seepage losses. Regulated water exchange and low apparent feed conversion ratio, helped in lowering the sedimentation rate (54.6-62.8 m^3 t^{-1} biomass). Higher net total water productivity (Rs. 4.4 m^{-3}), net consumptive water productivity (Rs. 8.5 m^{-3}) and ratio of the output value to the cost of cultivation (OV: CC, 2.15) also inferred that T_3 had a distinct edge over T_1 and T_2. In general, total water use varied greatly in aquaculture depending mainly upon the culture method used.

*(**Key words:** Consumptive water use, Indian major carp, Sedimentation rate, Water balance study, Water productivity, Water quality)*

The world is faced with a critical challenge of feeding the growing population that is expected to reach 9.6 billion by 2050. Global food and nutritional security must be achieved through increased food production, improved nutritional quality of food produced, and reduced food waste. An increase in food production must take place in a context where resources necessary for food production, such as land and water, are even scarcer in a more crowded world, while the world is required to change the ways it conducts economic activities in the face of global climate change. The rapid expansion of global aquaculture production has continued with no sign of reaching its peak and during the past three decades, global aquaculture production expanded at an average annual rate of over 8%. Global fish production has grown steadily in the last five decades, with food fish supply increasing at an average annual rate of 3.2 %, outpacing world population growth at 1.6%. Presently, India the 2nd largest fish producer, contribute 9.6 million tonnes *i.e.*, 5.7% of global finfish & shellfish production. India utilizes 45% of 2.44 million ha of ponds and tanks for freshwater aquaculture.

India's freshwater aquaculture production is mainly carp-based (Indian major carps, viz., *C. catla, L. rohita* and *C. mrigala*), contributing over 90% of the aquaculture production. The production system has been evolved from extensive to intensive with increasing inputs of feed and water supply. Water being the prime natural resource, its conservation, enhancing productivity and maintaining the quality are considered as paramount importance in the present day context. Usually, 'closed system' with little or 'zero' water discharge is practiced while few farmers do unplanned water exchange to minimize the waste loads from culture ponds (uneaten feed and metabolic wastes). However, the major problem associated with closed system is the rapid eutrophication in ponds, resulting from increasing concentrations of nutrients and organic matters over the culture period. On other hand, unplanned wasteful use of water in aquaculture is also limiting the development of this sector.

Uncertainty in monsoon rain, scare and limited availability of freshwater resource has forced in rethinking for wise-use of water in aquaculture sector.

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World in general and India in particular, the freshwater supply and reserve is now under threat due to increased population pressure and increasing demand of water in agriculture, industry and domestic sectors. The limited nature of the water resource, therefore, warrants a more holistic approach to water management. Further, freshwater aquaculture is a water-intensive endeavor and its future growth would be constrained by the freshwater availability (Verdegem and Bosma, 2009). As water will be no longer available for aquaculture in an unlimited manner, special efforts for quantifying the water requirement will ensure higher water productivity and profitability.

Due to the increasing demand to produce more per unit volume of water, water productivity and quantification of water requirement assume great importance in view of proper planning for judicious use of available water. Till date, no work has been carried out on aquacultural water productivity in grow-out culture of Indian major carps, except few preliminary works (Saha *et al*., 1997; Dasgupta *et al*., 2008; Mohanty *et al*., 2009). Similarly, no work has been carried out on quantification of optimum water requirement in polyculture of Indian major carps and freshwater prawn *Macrobrachium rosenbergii*. Very little basic work have also been carried out on water budgets based on pond measurements for different type of systems and climatic conditions (Boyd and Gross, 2000; Boyd *et al*., 2007; Verdegem *et al*., 2006; Verdegem and Bosma, 2009; Bosma and Verdegem, 2011). As water budgeting and its judicious use is a primary requisite towards development of protocols for best water management practice, an attempt was made to quantify the total and consumptive water use, sediment load and to study its impact on water quality and water productivity in the grow-out culture of Indian major carps and freshwater prawn *Macrobrachium rosenbergii* under recommended package of practice.

MATERIAL AND METHODS

Experimental set up

This study (21°28' 44'' N, 87° 02' 15'' E) was carried out at Balasore district, Odisha, India, during 2011-2012. During the experiment, "water exchange pattern" was taken as treatment [T_1- No water exchange, T_2- 10% water exchange (WE) on monthly basis, T_3- 10% WE on 'requirement' basis depending on the water quality variables (if the daily variation in average water pH > 1.0 or if morning dissolved oxygen (DO) < 3.0ppm)]. Each treatment had three ponds as replication. Pond size was 5000 m^2 each. Culture duration was 180 days.

Pond management

Pre-stocking pond preparation for freshwater composite fish-prawn culture included horizontal ploughing followed by application of lime ($CaCO_3$) at the rate of 500 kg ha^{-1} followed by longitudinal ploughing and application of lime ($CaCO_3$) at the rate of 250 kg ha^{-1}. After liming and water filling, raw cattle dung (RCD) at 7000 kg ha^{-1} as basal dose and fertilizer (Urea: Single Super Phosphate :: 1:1) at 3 ppm was applied. Seven days after pond preparation, stocking operation was carried out. Periodic manuring with RCD at the rate of 500 kg ha^{-1} and liming at 150 kg ha^{-1} were carried out at monthly interval to maintain plankton population in the eco-system. Artificial substrate, mainly broken asbestos and cement pipes, covering 10% of the bottom area of the pond was provided in a horizontal orientation for *M. rosenbergii* in order to prevent cannibalism during the moulting phase. Recommended stocking density (ICAR, 2005) of 5,000 fingerlings (30:30:40 :: Surface Feeder: Column Feeder: Bottom Feeder) and 10,000 Post-Larvae of *M. rosenbergii* ha^{-1} in composite fish culture was maintained. Stocking was carried out with proper acclimatization procedure. Management practices and inputs were same for all treatments and replications.

Physico-chemical parameters

Recommended minimum water depth (ICAR, 2005) of 2.0 m for freshwater composite fish-prawn culture was maintained for each treatment. Required depth was maintained on weekly basis either adding or withdrawing water from the experimental ponds. Major physico-chemical parameters of pond water, *e.g.*, total alkalinity, total suspended solids, dissolved organic matter and CO_2 were monitored *in-situ* every week between 0700-0800 hours and during 1500-1600 hours using standard methods (Biswas, 1993 and APHA, 1995). Temperature, pH, dissolved oxygen (DO) and transparency were recorded daily between 0700-0800 hours and during 1500-1600 hours using a multi-parameter water analyzer (YK-611, Yeo-Kal Electronics Pty. Ltd., Australia). NH_4^+ was determined spectro photometically with the indophenol blue method, while chlorophyll-*a* was determined using the acetone extraction method. Primary productivity was analyzed using the "Oxygen method" (APHA, 1995), while nutrient analysis following standard methods (Biswas, 1993). Plankton samples were collected at fortnightly intervals by filtering 50 l of water from each unit through a silk net (No. 25, mesh size 64 μm), preserved in 4% formaldehyde and later analyzed for quantitative estimation.

Sediment samples were collected twice from the pond during each crop period (*i.e.* before stocking and after harvesting) and analyzed for pH, available nitrogen, available phosphorus and organic carbon using standard methods. Estimation of sedimentation rate (m^3 t^{-1} biomass) was estimated as described by Mohanty, (2001).

Feeding management

Supplemental feeding was provided, in the form of moist dough, with a ratio of 60: 35: 5 (rice bran: mustard oil cake: fish meal) on a dry wet basis at the rate of 5%, 4%, 3% and 2.0% of mean body weight (MBW) twice a day (7.00-8.00 h and 16.00-17.00 h), during 1st, 2nd, 3rd and 4th month to harvesting, respectively. The quantity of daily feed was calculated based on average MBW, recorded through monthly sampling and at an assumed 80% survival. The estimated crude protein (%) of feed ingredients was 8.8, 37.3 and 52.4, respectively for rice bran, mustard oil cake and fish meal. Daily feed requirement, % feed used, and feed increment per day was estimated using formulas as described by Mohanty (1999). Apparent feed conversion ratio (AFCR) and feeding efficiency (FE) was estimated as follows:

AFCR = Total feed used (kg) / Net biomass gain (kg) ..(1)

FE = Biomass gain (kg) / feed used (kg) x 100 …..…. (2)

Growth and yield parameters

Weekly growth study was carried out by sampling prior to feeding, so that complete evacuation of gut was ensured. Weekly mean body weight (MBW in g), mean total length (cm), condition factor (Kn), average daily growth or per day increment (PDI in g), absolute growth (g), survival rate (%), and biomass (kg) was estimated using formulas as described by Mohanty (1999). Other growth parameters such as performance index (PI) and production-size index (PSI) were estimated as described by Mishra *et al*., (2013) while, the specific growth rate (SGR, in % d^{-1}) was estimated as follows:

SGR = ln final weight - ln initial weight / Days of culture (DOC) x 100 ....…(3)

Water budgeting

The general water balance equation, inflow = outflow ± change in volume (ΔV), can be used to make accurate estimates of water use by ponds for inland aquaculture. Water use in aquaculture may be classified as either total use or consumptive use. Total water use (TWU) is the sum of all possible inflows to aquaculture ponds such as precipitation (P), runoff (R), stream inflow, groundwater seepage (S_i), and management additions or regulated inflows (I) whereas, consumptive water use (CWU) includes the possible outflows such as evaporation (E), seepage (S_o), transpiration, overflow (O_f), intentional discharge or regulated discharge (D), and water in harvest biomass (about 0.75 m^3/t, Boyd *et al*., 2007) a negligible amount that can be ignored. Commercial aquaculture ponds seldom receive direct inflow from streams. Further, aquatic weeds are prevented from growing in and around edges of ponds, while water is rarely used for activities other than aquaculture. Therefore, stream inflow, and transpiration are seldom major factors. As embankment ponds are small watersheds, runoff is negligible and groundwater inflow is also seldom a factor (Boyd and Gross, 2000). Thus the appropriate equation is:

$$P + I = E + S_o + O_f + D \pm \Delta V \quad .....(4)$$

Further, the difference between the total and consumptive water use, refers to non-consumptive water use (NWU). Consumptive water use index (CWUI) that indicates the amount of water used per unit production in an aquaculture system could be calculated as shown below:

CWUI = CWU (m^3) / Production (kg) .....(5)

To estimate the CWU, a recording water level gauge was installed in each pond to measure the water loss (evaporation + seepage), the inflow and outflow during the experimental period. Further, to separate the evaporation from the total loss, evaporation was estimated using the following equation:

Pond evaporation (mm) = Pond-pan coefficient x Class-A pan evaporation (mm) ...(6)

Pond pan coefficient of 0.8, most appropriate for ponds, was used in the above equation as suggested by Boyd and Gross (2000). The pond seepage was quantified by subtracting the evaporation loss from the total loss.

Water productivity and economic efficiency

To evaluate the efficiency of water management, the gross total water productivity (GTWP), net total water productivity (NTWP) and net consumptive water productivity (NCWP) was calculated (Rupees m^{-3})

keeping the total volume of water used in to account as shown below:

GTWP = Total economic value of the produce (Rs.) / Total volume of water used (m^3) .....(7)

NTWP = Total economic value of the produce (Rs.) – Production cost (Rs.) / Total volume of water used (m^3) .....(8)

NCWP = Total economic value of the produce (Rs.) – Production cost (Rs.) / volume of consumptive water use (m^3) .....(9)

The ratio of the output value to the cost of cultivation (OV-CC ratio) was estimated (Mohanty *et al*. 2008). The cost of excavated pond, considering the life span up to 15 years, which is a fixed cost, was added (depreciated cost) to the yearly variable cost of cultivation. The cost of excavated pond was estimated to be Rupees 135,000 ha^{-1}. The operational cost includes: the cost of fish feed (Rs. 30.00 kg^{-1}), fish seed (Rs. 2.00 $fingerling^{-1}$), raw cow dung (Rs. 500.00 t^{-1}), labour (Rs. 100.00 man day^{-1}), lime (Rs. 7.50 kg^{-1}) and other cost such as cost of fuel, fertilizer etc. Similarly, the on-site selling price of fish, and freshwater prawn was Rs. 80.00, and Rs. 160.00 kg^{-1}, respectively.

Statistical analysis

Statistical analysis was carried out by using SAS, Version 9. Significance ($P < 0.05$) of all possible pairs of treatment means was evaluated using the Duncan's multiple range test.

RESULTS AND DISCUSSION

Water and sediment quality

The treatment-wise variations in the water and sediment quality parameters in freshwater composite fish-prawn culture under different water management protocols are presented in Table 1. Total suspended solids and the dissolved oxygen concentration show a decreasing trend with the advancement of the rearing period. Higher values of nitrite, nitrate, ammonia and total alkalinity were recorded towards the later part of the experiment. At any given point in time, except the total alkalinity and total suspended solids, the remaining water quality parameters and plankton population did not register any specific trend between the treatments. Various hydro-biological parameters prevailing in the

Table 1. *Treatment-wise variations in the water and sediment quality parameters in carp polyculture under different water management protocols*

PARAMETERS	No water exchange (T_1)	Periodic water exchange (T_2)	Regulated water exchange (T_3)
Water quality parameters			
Water pH	7.51 ± 0.17^{ab}	7.32 ± 0.11^{b}	7.64 ± 0.13^{a}
Dissolved Oxygen (ppm)	4.9 ± 1.2^{b}	6.1 ± 0.7^{a}	5.2 ± 1.1^{b}
Temperature (°C)	28.7 ± 0.6^{a}	28.5 ± 0.3^{a}	28.5 ± 0.5^{a}
Total alkalinity (ppm)	89 ± 8^{c}	96 ± 10^{b}	108 ± 7^{a}
Dissolved Organic Matter (ppm)	4.9 ± 0.2^{a}	3.7 ± 0.4^{b}	3.5 ± 0.3^{b}
Total Suspended Solids (ppm)	187 ± 16^{c}	235 ± 13^{a}	223 ± 10^{b}
NH_4^+ water (ppm)	0.59 ± 0.03^{b}	0.68 ± 0.03^{a}	0.65 ± 0.02^{ab}
Chlorophyll-a (mg m^{-3})	44.3 ± 5.3^{a}	37.7 ± 4.2^{b}	43.1 ± 3.2^{a}
Total plankton (units l^{-1})	$4.6x10^4 \pm 1.4x10^{3a}$	$3.7x10^4 \pm 1.1x10^{3b}$	$3.9x10^4 \pm 1.3x10^{3\ ab}$
Nitrite – N (ppm)	0.03 ± 0.00^{a}	0.04 ± 0.01^{a}	0.03 ± 0.01^{a}
Nitrate – N (ppm)	0.36 ± 0.08^{a}	0.37 ± 0.06^{a}	0.36 ± 0.09^{a}
Phosphate – P (ppm)	0.26 ± 0.04^{a}	0.21 ± 0.03^{b}	0.21 ± 0.04^{b}
Sediment quality parameters			
Available-N in soil (mg 100 g^{-1})	20.3 ± 0.3^{a}	19.3 ± 0.3^{c}	19.8 ± 0.2^{b}
Available-P in soil (mg 100 g^{-1})	2.11 ± 0.07^{b}	2.23 ± 0.08^{a}	2.21 ± 0.06^{a}
Organic carbon in soil (%)	0.63 ± 0.01^{a}	0.64 ± 0.01^{a}	0.61 ± 0.01^{b}
Soil pH	6.95 ± 0.07^{a}	7.02 ± 0.08^{a}	7.04 ± 0.09^{a}

All values are mean ± SD. Values with different superscripts in a row differ significantly ($P<0.05$).

different treatments were within the optimum ranges and did not fluctuate drastically. This was probably due to the similar levels of inputs in all the treatments in the form of organic manure, inorganic fertilizer and periodic liming. The decreasing trend in DO in all the treatments with the advancement of the fish rearing period, attributed to the fluctuations in plankton density and a gradual increase in biomass, resulting in higher oxygen consumption. During the study period, water exchange was carried out once as daily morning DO fall below 3.0 ppm in T_3 on 166th day. However, in this study the weekly average DO level did not drop below 3.7 ppm in any treatment. Gradual increases in nitrite, nitrate, and ammonia were attributed to intermittent fertilization, increased levels of metabolites and decomposition of unutilized feed in the absence of water replenishment (Mohanty *et al*., 2010). In general, the poor growth performance of cultured species takes place at pH < 6.5, while higher values of total alkalinity (> 90 ppm) indicates a more productive eco-system (Mohanty *et al*., 2009). In this study, the recorded minimum and maximum range of total alkalinity was 81 ppm to 115 ppm, which was maintained due to periodic liming. An overall improved water quality was recorded in T_2 (Table 1) followed by T_3 and T_1, probably due to the intensity of water exchange.

Soils of the experimental ponds were clay, having an acidic pH (6.6-6.8). The composition of sand, silt and clay was 33.6%, 19%, and 47.4 %, respectively. Organic carbon (%), available N and P in soil (mg 100 g^{-1}) varied between 0.26-0.39, 8.9-11.1 and 1.08-1.42, respectively at the beginning of the experiment which was improved later (Table 1). This was likely due to (1) the additional nutrients from the fish feed and feces, (2) fish grazing on the photosynthetic aquatic biomass and other components of the system, thereby aiding in nutrient cycling (Mohanty *et al*., 2009), minimizing N losses and facilitating P release from the sediment (Breukelaar *et al*., 1994). No distinct trends between the treatments were observed and the sediment characteristics of the different treatments were indicative of a medium productive soil group (Banerjee, 1967).

Quantification of water requirement

Water budgeting under different water management protocols was carried out (Fig.1) to estimate the consumptive and non-consumptive water use. Under freshwater IMCs-prawn composite culture, treatment-wise estimated total water use (TWU)/ total crop water requirement ha^{-1} (culture duration-180d) was 3.69, 4.62 and 3.9 ha-m in T_1, T_2 and T_3, respectively while the computed consumptive water use index (CWUI, m^3 kg^{-1} biomass) was 6.62, 9.31 and 7.08, in T_1, T_2 and T_3, respectively. Evaporation and seepage losses contribute significantly to CWU. Average seepage loss was 4.4 mm d^{-1}, while the average evaporation loss was 4.7mm d^{-1}. Evaporation loss is a function of climatic condition and culture duration. On average, 5.2 m^3 water per kg production is consumed through evaporation from ponds (Bosma and Verdegem, 2011). However in the present study, evaporation loss was 2.9-3.1 m^3 water kg^{-1} production in freshwater IMCs-prawn composite culture. Water use in ponds usually varies with the intensity of production, frequency and amount of water exchange employed. Higher the amount of water exchange, higher is the TWU as in case of T_2. Fish production typically requires TWU between 4 to 8 m^3/kg fish in embankment ponds, 8 to 16 m^3/kg fish in watershed ponds (Boyd, 2005, Boyd *et al*., 2007). Presently, on-farm water use in aquaculture can be as low as 0.5–0.7 m^3 in super-intensive re-circulation systems and as high as 45 m^3 of water per kilogram of produce in extensive pond system (Verdegem *et al*., 2006). In general, total water use varies greatly in aquaculture depending mainly upon the culture method used.

Growth and yield performance

At a fixed population density, irrespective of treatments, higher growth rate was recorded for *C. catla* followed by *C. mrigala* (Table 2). Species-wise growth performance of fish was significantly lower (P<0.05) in T_1 than T_3 and T_2. Similarly, the growth performance of *M. rosenbergii* was significantly lower (P<0.05) in T_1 than T_2 and T_3. Species-wise similar trend was also recorded in case of PDI, SGR, PI and PSI (Table 2 and 3).

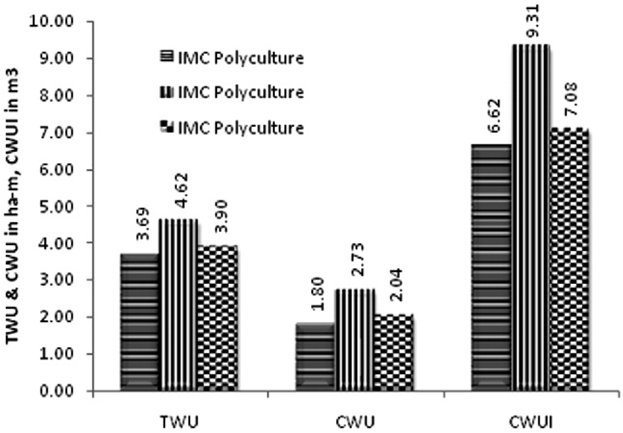

Fig. 1. *TWU, CWU and CWUI in IMCs poly under varying water management protocols*

Table 2. *Species-wise growth and survival performance of Indian major carps and M. rosenbergii under different water management protocols*

Treatment	Species reared	MBW (g)	PI	PSI	SGR (% d^{-1})	SR%
No water exchange (T_1)	*C.catla*	$621.8±3.17^c$	$279.4±6.1^b$	$543.7±12.0^c$	$1.10±0.005^c$	$93.8±2.1^a$
	L.rohita	$418.7±3.54^b$	$198.7±3.7^c$	$247.1±3.7^c$	$1.33±0.005^b$	$94.0±2.6^a$
	C.mrigala	$433.5±6.06^b$	$200.3±9.7^a$	$348.6±20.6^b$	$1.27±0.005^b$	$92.7±3.2^a$
	M.rosenbergii	$54.2±0.37^b$	$24.7±0.4^b$	$24.5±0.5^b$	$4.16±0.005^b$	$83.4±2.6^a$
Periodic water exchange (T_2)	*C.catla*	$654.5±4.09^a$	$307.6±2.0^a$	$626.2±3.9^a$	$1.13±0^a$	$97.4±1.3^a$
	L.rohita	$439.1±3.68^a$	$214.9±1.3^a$	$279.9±4.1^a$	$1.35±0.005^a$	$96.7±0.3^a$
	C.mrigala	$455.5±2.29^a$	$211.8±3.1^a$	$385.1±7.2^a$	$1.3±0^a$	$92.7±0.8^a$
	M.rosenbergii	$58.1±0.7^a$	$27.5±0.7^a$	$28.8±0.6^a$	$4.20±0.005^a$	$85.3±0.6^a$
Regulated water exchange (T_3)	*C.catla*	$647.9±2.8^b$	$302.2±1.3^a$	$609.6±4.3^b$	$1.12±0.005^b$	$96.7±0.4^a$
	L.rohita	$432.3±5.85^a$	$207.9±2.4^b$	$266.1±5.5^b$	$1.35±0.01^a$	$94.9±1.3^a$
	C.mrigala	$448.5±3.04^a$	$209.4±1.5^a$	$376.1±2.9^a$	$1.29±0^a$	$93.5±1.2^a$
	M.rosenbergii	$58.4±1.21^a$	$26.6±0.05^a$	$28.4±0.5^a$	$4.20±0.01^a$	$83.5±2.7^a$

All values are mean ± SD. Species-wise values with different superscripts in a column differ significantly ($P<0.05$). MBW: mean body weight at the time of harvest, SGR: specific growth rate, SR: survival rate, PI: performance index. Stocking size of *C.catla, L.rohita, C.mrigala*, and *M.rosenbergii* was 85.5g, 38.0g, 44.0g, and 0.03g respectively. Days of culture=180d.

Table 3. *Treatment-wise production performance and sediment load (dry volume) under different water management protocols*

Treatment	Productivity(t ha^{-1})	FE (%)	AFCR	Sediment quantity, m^3 t^{-1} biomass
No water exchange (T_1)	$2.72±0.065^b$	$50.7±1.0^b$	$1.78±0.04^a$	71.3^a
Periodic water exchange (T_2)	$2.93±0.017^a$	$52.6±0.6^a$	$1.72±0.02^b$	54.6^b
Regulated water exchange (T_3)	$2.88±0.004^a$	$52.0±0.6^a$	$1.74±0.02^b$	62.8^b

All values are mean ± SD. Species-wise values with different superscripts in a column differ significantly ($P<0.05$). WSA: water surface area, PSI: production-size index, FE: feed efficiency, AFCR: apparent feed conversion ratio. Days of culture= 180d

This was probably due to the water exchange that helps in reducing organic and nutrient load, toxic metabolites, turbidity, and promotes growth (Mohanty, 2000). In this experiment, the lower rates of water exchange in T_3 and periodic water exchange in T_2, showed improved water quality (Table 1) and overall crop performance (Table 3) over the zero water exchange. Although intensity of water exchange was more in T_2, significant variation ($P<0.05$) in overall growth and yield was not recorded between T_2 and T_3. However, significantly higher yield ($P<0.05$) in both T_2 and T_3 over T_1, was probably due to water exchange that improved the rearing environment. Similar trend was also recorded for FE.

In general, significant variation ($P<0.05$) in survival rate and AFCR among different treatments due to water exchange protocols was not recorded. Mohanty (2000) reported that that excess water exchange (daily/weekly) has no significant effect on survival rate, except in maintaining a cleaner aquatic environment. Water exchange does not influence the overall crop performance (Good *et al*., 2009) and is not necessary in most types of pond aquaculture (Boyd and Tucker, 1998). Higher survival in all the treatments were probably due to the stocking size (advanced fingerlings), as they are likely to be hardier and therefore, more able to adapt to pond conditions. Keeping the overall growth performance, water productivity and economic efficiency in view, T_3 is considered the best water management protocol followed by T_2 and T_1.

Sediment load

Usually, nutrients, organic matter and suspended solids cause sedimentation in aquaculture ponds. Under different water management protocols, treatment-wise sediment load ranged between 54.6-71.3 m^3 t^{-1} biomass in composite fish-prawn culture (Table 3). Higher the intensity of water exchange, lower is the sediment

Table 4. *Ratio of the output value (OV) to the cost of cultivation (CC) and treatment-wise GTWP, NTWP and NCWP under different water management protocols*

Treatment	Output Value (Rs. ha^{-1})	Cultivation Cost (Rs. ha^{-1})	Net return (Rs. ha^{-1})	OV-CC ratio	GTWP (Rs. m^{-3})	NTWP (Rs. m^{-3})	NCWP (Rs. m^{-3})
T_1	303,262	155,584	147,678	1.94	8.2	4.0	8.2
T_2	329,148	161,176	167,972	2.04	7.1	3.6	6.2
T_3	322,871	150,384	172,487	2.15	8.3	4.4	8.5

GTWP- gross total water productivity, NTWP- net total water productivity, NCWP- net consumptive water productivity. The farm gate selling prices of harvested fish and *M. rosenbergii* were Rs.80.00 and Rs.160.00 kg^{-1} respectively

quantity. Further, AFCR plays a key role in sediment loading. Higher the AFCR, higher is the sedimentation rate (Table 3). A good AFCR, helps in maintaining good pond bottom and minimizes the sediment quantity (Mohanty, 2001).

Water productivity and economic efficiency

In this experiment, under different water management protocols, treatment-wise gross total water productivity (GTWP), net total water productivity (NTWP) and net consumptive water productivity (NCWP) in composite fish-prawn culture are presented in Table 4. In composite fish-prawn culture, regulated water exchange protocol (T_3) performed well (higher NTWP and NCWP) against periodic water exchange (T_2) and no water exchange (T_1). However, lower NTWP and NCWP in T_2 against T_1 was probably due to excess water exchange that enhanced the operational cost (Table 4). Higher OV-CC ratio, ratio of the output value (OV) to the cost of cultivation (CC) also infers that regulated water exchange has a distinct edge over the no water exchange protocol (Table 4**).** Boyd and Tucker (1998) reported that water exchange is not necessary in most types of pond aquaculture and also has no influence on the overall crop performance (Good *et al*., 2009). However, regulated water exchange instead of excess water exchange helps in reducing organic and nutrient load, toxic metabolites, improves water quality and promotes growth (Mohanty, 2000). Even with the implementation of water cutback approach, pond aquaculture is a water- intensive endeavour which consumes more water per unit of area than irrigated agriculture. However, the value of aquacultural production per unit of water used greatly exceeds that of irrigated agriculture (Boyd and Gross, 2000).

CONCLUSIONS

Water budgeting and quality monitoring followed by pond management are the two major requirements in improving aquaculture performance and productivity. Application of better management practices is the main approach for improving the aquaculture performance to make production more resource efficient and environmentally responsible. Minimization of unnecessary water exchange in aquaculture operations, also perceived as a way to increase water productivity and profits. Understanding the principles of pond water management and aquaculture with an effort to optimize, integrate and disseminate such a combined methodology is needed towards a sustainable blue revolution.

REFERENCES

APHA, (1995). *Standard methods for examination of water and waste water*. 19th edition. American Public Health Association. Washington, D.C., U.S.A. 874p.

Banerjee, S. M. (1967). Water quality and soil condition of fishponds in some states of India in relation to fish production. *Indian Journal Fisheries* **14**: 115-144.

Biswas, K. P. (1993). *Fisheries Manual*. Bhagabat Press and Publishers, Cuttack, Orissa, India.

Bosma, R. H. and Verdegem, M. C. J. (2011). Sustainable aquaculture in ponds: Principles, practices and limits. *Livestock Science* **139**: 58-68.

Boyd, C. E. and Gross, A. (2000). Water use and conservation for inland aquaculture ponds. *Fisheries Management and Ecology* **7**(1-2): 55-63.

Boyd, C. E. and Tucker, C. S. (1998). *Pond aquaculture water quality management*. Boston, MA: Kluwer Academic Publishers.

Boyd, C. E., Tucker, C. S., Mcnevin, A., Bostick, K. and Clay, J. (2007). Indicators of Resource Use Efficiency and Environmental Performance in Fish and Crustacean Aquaculture. *Reviews in Fisheries Science* **15**: 327–360.

Breukelaar, A.W., Lammens, E. H. R. R., Breteler, J. G. P. K. and Tatrai, I. (1994). Effects of benthivorous bream (*Abramis brama*) and carp (*Cyprinus carpio*) on sediment resuspension and concentrations of nutrients and chlorophyll-a. *Freshwater Biology* **32**: 113-121.

Dasgupta, S., Pandey, B. K., Sarangi, N. and Mukhopadhyay, P. K. (2008). Evaluation of water productivity and fish yield in sewage-fed vis-a`-vis fertilized based carp culture. *Bioresource Technology* **99**: 3499–3506.

Good, C., Davidson, J., Welsh, C., Brazil, B., Snekvik, K. and Summerfelt, S. (2009). The impact of water exchange rate on the health and performance of rainbow trout *Oncorhynchus mykiss* in water recirculation aquaculture systems. *Aquaculture* **294**: 80–85.

ICAR, (2005). *Aquaculture Technologies for Farmers*. Indian Council of Agricultural Research. New Delhi, India. 104 p.

Mishra, A., Ghosh, S., Mohanty, R. K. and Brahamand, P. S. (2013). Performance evaluation of a rehabilitated minor irrigation project and augmentation of its water resource through secondary storage reservoir. *Agricultural Water Management* **128**(2013): 32- 42.

Mohanty, R. K. (1999). Growth performance of *Penaeus monodon* at different stocking densities. *Journal of Inland Fisheries Society India* **31**(1): 53-59.

Mohanty, R. K., Jena, S. K., Thakur, A. K. and Patil, D. U. (2009). Impact of high-density stocking and selective harvesting on yield and water productivity of deepwater rice-fish systems. *Agricultural Water Management* **96**(12): 1844-1850.

Mohanty, R. K., Thakur, A. K., Ghosh, S., Mohanty, S. and Patil, D. U. (2010). Performance evaluation of concurrent rice-fish-prawn culture with and without cull harvesting. *Aquaculture Research* **41**: 1402-1412.

Mohanty, R. K. (2000). Performance evaluation of different water exchange pattern on growth and survival of *Penaeus monodon* (Fabricius). *Journal of Aqua*culture **8**: 67-71.

Mohanty, R. K. (2001). Feeding management and waste production in semi-intensive farming of *Penaeus monodon* (fab.) at different stocking densities. *Aquaculture International* **9:** 345–355.

Mohanty, R. K., Jena, S. K., Kumar, A., Sahoo, N. and Roy Chowdhury, S. (2008). *Rice-fish Culture: An Ingenious Agricultural Heritage System*. Research Bulletin-42. DWM, ICAR, India. 54p.

Saha, C., Mohapatra, B. C. and Giri, S. S. (1997). Growth studies of three major carps of India in flow-through aquaculture system. *Journal of Aquaculture Tropical* **12**(2): 97-102.

Verdegem, M. C. J. and Bosma, R. H. (2009). Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use. *Water Policy* 11, Supplement **1**: 52-68.

Verdegem, M. C. J., Bosma, R. H. and Verreth, J. A. J. (2006). Reducing water use for animal production through aquaculture. *Water Resources Development* **22**(1): 101-113.