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ORIGINAL ARTICLE

Water budgeting for culture of *Penaeus vannamei* (Boone, 1931) in earthen grow-out ponds using inland saline groundwater

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Abstract

Efficient water budgeting for various species will help in establishing database for providing practical solutions to the aquaculture sector's water crisis. Hence, a 90-day study was conducted to evaluate the requirement of water for culture of *Penaeus vannamei* in inland saline groundwater. The earthen grow-out ponds (0.1 ha) were stocked with postlarvae of *P. vannamei* (2.50 ± 0.01 g) at three different stocking densities, that is 30/m^2 (T1), 45/m^2 (T2) and 60/m^2 (T3) respectively. The total quantity of water supplied and evaporation and seepage losses were measured on a daily basis. The rainfall and surface runoff were measured in the event of rainfall. The water quality parameters were analysed once in 10 days and were found to be within the permissible limit. The mean total consumption of water for T1, T2 and T3 was 2093.33 ± 6.66, 2099.30 ± 3.33 and 2092.96 ± 5.77 m^3 respectively. The survival and yield of *P. vannamei* in treatments T1, T2 and T3 were 80.49 ± 0.61%, 72.06 ± 0.74% and 68.70 ± 1.45%; and 283 ± 1.53, 322 ± 3.46 g and 311 ± 3.79 kg respectively. The consumptive water use index was significantly less ($p > 0.05$) in T2 (6.53 ± 0.07 m^3/kg) followed by T3 (6.74 ± 0.08 m^3/kg) and T1 (7.41 ± 0.04 m^3/kg). The water productivity of *P. vannamei* was significantly higher ($p < 0.05$) in T2 (0.153 ± 0.002 kg/m^3) followed by T3 (0.148 ± 0.002 kg/m^3) and T1 (0.135 ± 0.001 kg/m^3). Considering the total quantity of water used and the shrimp produced from the earthen grow-out ponds using inland saline groundwater, a stocking density of 45/m^2 and a water budget of 6.53 m^3/kg production of shrimp could be recommended as optimum.

KEYWORDS
P. vannamei, stocking density, inland saline groundwater, water productivity

1 | INTRODUCTION

Aquaculture is projected as a promising food-producing sector for meeting the world's rising protein demand. Since fish production totally depends on water as its main resource, utmost care should be taken for every drop of water spent on the farm. The underground water is getting salinized due to many natural and anthropogenic activities, and this has led to major problems for agriculture production. Approximately, 8.7 million hectares of land in India is affected by salinization and nearly 40% of this salt-affected land is located in the north western region of India (Allan et al., 2009).

In most of the arid and semi-arid areas, sources of good quality water are limited and shrinking day by day because of their diversion to other sectors. For reducing the gap between freshwater demand and supply, water supply needs to be augmented by saline groundwater. In the agricultural sector, there are many ways to use saline groundwater such as brackishwater aquaculture (Verma, Gupta, & Isaac, 2010; Verma et al., 2013) and cyclic use of water (Verma et al., 2014). Similarly, in the aquaculture sector, there is huge potential to use saline groundwater. Aquaculture is the best way to utilize the inland saline groundwater in order to achieve sustainability for maintaining the ecosystem smoothly. In India, the use of saline groundwater for aquaculture has been identified as a high-priority research area (Allan et al., 2009; Sharma & Singh, 2015). For reducing the use of freshwater and increasing the use of saline groundwater, various technologies like aquaponics using freshwater (John et al., 2022; Nuwansi et al., 2017, 2020, 2021; Shete et al., 2013, 2015, 2017) and aquaponics using saline groundwater (Thomas et al., 2019, 2021) for various fish in aquaculture. Furthermore, the biofloc technology is also aimed at reducing the use of water for aquaculture (Ahmad et al., 2019; Ezhilarasi et al., 2019; Nageswari et al., 2020, 2022).

Water losses comprise seepage, evaporation and percolation, which represent the major water losses in pond aquaculture systems (Verdegem et al., 2006). In order to protect the water resources, there is a need to do a systematic water budget on individual species, and it will be one of the ways in sustainable development of aquaculture. For using the inland saline groundwater, important factors to be considered are fish species, the stocking density of fish, the quantity of water required and, finally, the water productivity.

Penaeus vannamei, commonly referred to as Pacific white shrimp, became a popular candidate species in Indian shrimp farming due to its high economic importance in recent years. The farming of *P. vannamei* is successful due to its fast growth rate, high tolerance capacity in crowded conditions, lower dietary requirement and tolerance to wide range of salinity and temperature (Lakra et al., 2014). Many nations practise the cultivation of marine fish and shrimp in low salinity water (McNevin et al., 2004). When shrimps were acclimated to inland saline groundwater, the growth and survival of *P. vannamei* enhanced with the age of postlarvae (Davis et al., 2002). ICAR-Central Institute of Fisheries Education (CIFE), Mumbai, India, has successfully developed culture practices for profitable aquaculture of *P. vannamei* in inland saline groundwaters at its Regional Centre, Rohtak, Haryana (CIFE, 2015).

Many researchers have worked on water budgeting for fish hatcheries and aquafarms for culture of various fish species. Water requirement for producing single spawn and single fry in carp hatchery was calculated as 0.56 and 4.86 L respectively (Verma, Jacob, & Prakash, 2010). The requirement of water for carp production in semi-intensive culture system was found to be 10.3 m^3/Kg (Sharma et al., 2013). The optimum stocking density of 50 postlarvae per m^2 for *Litopenaeus vannamei* resulted in total water use of 3.42×10^4 m^3 for one hectare (Mohanty et al., 2018). However, there has not been extensive research done and published literature available on water budgeting and water productivity for the grow-out culture of *P. vannamei* in earthen ponds with different stocking densities using inland saline groundwater. For increasing water productivity in shrimp culture ponds using inland saline groundwater, the stocking density of shrimps needs to be optimized.

Considering the importance of water budgeting, this study was conducted to estimate the requirement of water for unit production of *P. vannamei* in earthen grow-out ponds using inland saline groundwater.

2 | MATERIALS AND METHODS

2.1 | Experimental site

The experiment was carried out at ICAR-Central Institute of Fisheries Education (CIFE), Rohtak, Haryana, India (28°53′43″N, 76°36′23″E). The water used for the experiment was taken from a tube well (about 50–60 feet deep from the ground level) located in the fish farm area, and its average salinity was 12 ppt (Table 1). The water drawn from the tube well was supplied to the experimental ponds through a cement concrete feeder channel.

2.2 | Design of experiment and experimental procedure

The experiment was conducted for a period of 90 days in nine earthen grow-out ponds of 0.1 ha (50 × 20 m) surface area each and 1.5 m depth (Figure 1a). The experiment comprised of three treatments T1, T2 and T3 in triplicates with three different stocking densities of 30, 45 and 60/m^2 respectively. Before filling the ponds with inland saline groundwater, de-weeding was done from the sloping surface of the pond dike. The stocking densities viz., 30, 45 and 60/m^2 were decided based on the CAA (2005) guidelines. Before stocking, the pond bottom was ploughed up to a depth of 10 to 15 cm with the help of tiller followed by drying out of the pond for a week. The ponds were treated with lime at the rate of 150 kg/ha in order to maintain the sanitation of pond bottom and biological productivity. The graduated water-level measuring staffs (2 numbers) were fixed on the bottom of each pond at two different locations before filling the pond with water to monitor the water level in the experimental ponds (Figure 1b). The evaporation of water from the ponds was estimated by using a stainless steel evaporation pan with a diameter of 1206 mm

TABLE 1 Physico-chemical parameters of tube well water

Parameters	Value
Temperature (°C)	24
Salinity (g/L)	12.0
DO (mg/L)s	4.6
pH	8.01
Free carbon-dioxide (mg/L)	Nil
Alkalinity (mg/L)	230
Hardness (mg/L)	1900
Calcium (mg/L)	218
Magnesium (mg/L)	286
Potassium (mg/L)	31.2
Ammonia nitrogen (mg/L)	0.03
Nitrite nitrogen (mg/L)	0.008
Nitrate nitrogen (mg/L)	0.02

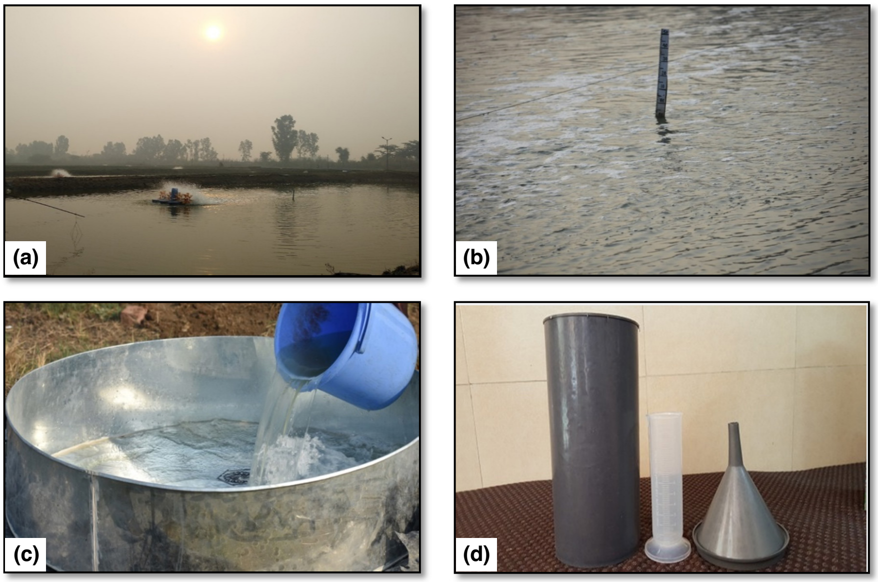

FIGURE 1 (a) Site of the experiment, (b) graduated staff, (c) evaporation pan and (d) rain gauge equipment

(47.5 inches) and a depth of 54 mm (10 inches) in accordance with the dimensions of 'Class A' evaporation pan (Figure 1c) prescribed by Caissie (2011). The evaporation pan was installed on a levelled surface of the crest of the pond dike. A rain gauge (Brand: The Curious brain) was bought from the local market and placed on the pond dike in an open area to measure the precipitation level in the pond (Figure 1d). Before stocking, the ponds were fertilized with inorganic fertilizer (Muriate of potash) at the rate of 150 kg /0.1 hectare as potassium concentration was very low in inland saline water as compared to natural sea water. The specific pathogen-free (SPF) *L. vannamei* PL were procured from a commercial shrimp hatchery approved by Coastal Aquaculture Authority (CAA) in Andhra Pradesh, India. The PL were acclimatized in separate nursery ponds available at the fish farm. A couple of weeks after filling the experimental ponds with inland saline groundwater, *P. vannamei* postlarvae (PL_{20}) with an average initial weight of 2.48 ± 0.01 g, 2.52 ± 0.01 g and 2.50 ± 0.01 g were stocked in the T_1, T_2 and T_3 ponds, respectively, as per the required stocking density corresponding to the treatment. The stocking density of postlarvae of *P. vannamei* in different treatments was 30/m^2 (75 kg), 45/m^2 (112.5 kg) and 60/m^2 (150 kg) in T1, T2 and T3 respectively. Various water and soil quality parameters were monitored during the culture period. The sampling was done at an interval of 10 days during the experimental period of 90 days.

2.3 | Monitoring of water and soil quality parameters

The experimental grow-out ponds were filled with inland saline groundwater drawn from the tube well located near the grow-out ponds in the fish farm and a storage level of 1 m was maintained. Throughout the experimental period of 90 days, the designed water level was maintained by adding new water into the pond on a weekly basis. The pond water was sampled once in 10 days for measuring various physico-chemical parameters of water quality viz., temperature, salinity, pH, dissolved oxygen, alkalinity, total hardness, ammonia, nitrate, nitrite, potassium, calcium and magnesium (APHA, 2005; Cataldo et al., 1975). During the culture period, the soil was sampled from the bottom of each pond once a month and the soil quality parameters viz., soil colour, soil pH, soil texture (bouyoucos hydrometer method), soil water retention capacity (Piper, 1967), organic carbon (Walkley & Black, 1934), organic matter, total nitrogen (standard Kjeldhal method) and phosphorous (standard phosphate adsorption method) were determined.

2.4 | Grow-out management and growth parameters

The commercial shrimp feed was procured from ABIS shrimp feed company. The composition of shrimp feed was 35% (protein), 6.5% (Fat), 2% (Fibre) and 12% (Moisture). Initially, shrimps were fed thrice a day with commercial pellet feed @ 5% of the body weight and finally reduced to 3% and 2% after 60 and 80 days of culture respectively. A check tray was installed in each pond to observe the feeding performance of shrimp. The feeding rate was modified based on the total estimated shrimp biomass by sample cast netting. Check trays were monitored regularly, and periodic sampling was done. Towards the end of the culture period, the feed intake decreased gradually due to a decline in water temperature owing to the winter season. Sampling was done at a regular interval of 15 days to monitor the health, growth and average body weight by repeated cast netting throughout the pond. Three to four casts were done to get a representative sample in 0.1 ha shrimp grow-out pond. Growth parameters viz., percentage weight gain, feed conversion ratio (FCR), feed efficiency ratio (FER) and specific growth rate (SGR) were analysed (Haridas et al., 2017; Nuwansi et al., 2019).

2.5 | Water budgeting analysis

The outflow and water losses include seepage, evaporation, regulated outflow and overflow from the pond. According to Boyd (1985), water budgeting accounts for the quantity of water in inflow, outflow and change in storage volume. The hydrological equation is

$$\text{Inflow} = \text{outflow} \pm \text{change in storage volume} \quad (1)$$

Aquaculture ponds often have a small watershed and are built in regions where groundwater inflow is not present (Boyd, 1982). Rainfall, runoff and water from an outside source such as a well, spring, stream and reservoir contribute to water gains in aquaculture ponds. Evaporation, seepage and overflow or regulated outflow are the sources of water loss in a fish pond (Green & Boyd, 1995). As a result, the above hydrological equation is modified to include levee and watershed ponds. The watershed of a levee pond is simply the inside slope of the levee, and as a result, runoff is a minor factor (Yoo & Boyd, 1994).

As a result, a levee pond's water budget may be represented as follows:

$$P + I + RO = (S + E) + \Delta V \quad (2)$$

where P = precipitation; I = inflow from well, stream or reservoir; RO = runoff; S = seepage; E = evaporation; and ΔV = change in the storage volume.

$$\text{Pond evaporation (mm)} = \text{Pond pan coefficient} \times \text{class A Pan evaporation} \quad (3)$$

According to Boyd and Gross (2000), the pond pan coefficient of 0.8 is best suited for ponds. Evaporation loss is subtracted from the total loss to calculate the seepage of water from pond. The following formula was used to determine the CWUI (consumptive water use index) (Mohanty et al., 2018)

$$\text{CWUI} = \text{Consumptive water use (CWU) in } m^3 / \text{Fish production in kg} \quad (4)$$

The efficiency of water management and water productivity (WP) in kg/m^3 was estimated based on the formula as the ratio between the actual yield achieved (Ya) and the total water use (TWU) (Mohanty et al., 2016).

2.6 | Ethics statement

The guidelines of the Committee for the Purpose of Control and Supervision of Experiments on Animals, Ministry of Environment and Forests (Animal Welfare Division), Govt. of India, were followed for the experiments on animals.

2.7 | Statistical analysis

Statistical analysis of the growth and physico-metabolic parameters was performed using SPSS 22.0 for Windows. One-way analysis of variance (ANOVA) was done followed by a post hoc mean comparison using Duncan's multiple range tests. All statistical tests were done for a statistical significance level of ($p < 0.05$).

3 | RESULTS

3.1 | Water and soil quality parameters under different stocking densities

The water quality parameters were monitored regularly for different treatment groups to observe the fluctuations, and the same are presented in Table 2. The water temperature of the different experimental ponds was measured and was found to be in the range of 15–29°C, and the water temperature gradually decreased during the winter. Dissolved oxygen (DO) concentration was found to be in the range of 4.0–6.7 mg/L throughout the culture period. The ammonia nitrogen (NH_4^+-N), nitrite nitrogen (NO_2-N) and nitrate nitrogen (NO_3-N) concentrations in the water of all the experimental ponds were found to be in the range of 0.03–0.25, 0.016–0.056 and 0.09–0.48 mg/L respectively. The important minerals such as calcium, magnesium and potassium were measured. The calcium, magnesium and potassium levels of all the experimental ponds were found to be within the range of 150–300, 290–690 and 20–80 mg/L respectively. The alkalinity and hardness were in the range of 160–295 and 1526.70–3340.00 mg/L respectively. The pond bottom soil of the experimental ponds was analysed to assess the pond bottom's chemical and biological characteristics. The pH of the soil was found to be in the range of 7.4–8.5. During the culture period, the pond bottom soil was analysed for soil texture. The water retention capacity of soil was found to be the range of 40%–46%. Organic carbon, total nitrogen and phosphorous in the soil were found to be in the range of 1.2%–2.25%, 80–120 and 5.8–6.4 mg/100 g respectively. The increasing trend observed in the soil quality parameters is presented in Table 3.

3.2 | Water budgeting under different stocking densities

A water budgeting study was carried out under different stocking densities to estimate the total water use (TWU), non-consumptive water use and consumptive water use index (CWUI). During the culture period of 90 days, the total quantity of water used for culture of *P. vannamei* in different treatments was found to be 2093.33 ± 6.66, 2099.66 ± 3.33 and 2092.96 ± 5.77 m^3 in treatments T1 (30/m^2), T2 (45/m^2) and T3 (60/m^2) respectively. The consumptive water use index (CWUI), that is water requirement for unit production of *P. vannamei* in treatments T1, T2 and T3, was found to be 7.41 ± 0.04, 6.53 ± 0.07 and 6.74 ± 0.08 m^3/kg respectively. The mean evaporation and seepage rates in three treatments T1 (30/m^2), T2 (45/m^2) and T3 (60/m^2) were found to be 369.60 ± 4.83, 370.40 ± 6.66 and 369.73 ± 5.47 m^3; and 629.40 ± 6.63, 634.60 ± 8.79 and 628.93 ± 2.94 m^3 respectively (Table 4).

TABLE 2 Physico-chemical parameters of water during the experimental period of 90 days

Parameters	Range	T1 (30/m^2)	T2 (45/m^2)	T3 (60/m^2)
Temperature (°C)	15–29	22.58 ± 0.05	22.77 ± 0.05	22.80 ± 0.06
Salinity (g/L)	12–14	12.73 ± 0.10	12.85 ± 0.03	12.88 ± 0.24
DO (mg/L)	4.0–6.7	5.85 ± 0.05	5.55 ± 0.0	5.30 ± 0.01
pH	8.1–8.6	8.36 ± 0.00	8.39 ± 0.01	8.42 ± 0.02
Free carbon-dioxide (mg/L)	Nil	Nil	Nil	Nil
Alkalinity (mg/L)	160–295	250.42 ± 2.13	257.24 ± 2.34	269.09 ± 1.36
Hardness (mg/L)	1527–3340	2660 ± 27.01	2846.97 ± 53.20	3006.67 ± 32.71
Calcium (mg/L)	150–300	223.88 ± 3.28	246.94 ± 3.59	253.70 ± 3.26
Magnesium (mg/L)	290–690	542.76 ± 7.04	573.24 ± 7.71	580.61 ± 4.05
Potassium (mg/L)	20–80	53.73 ± 0.92	53.98 ± 0.42	55.04 ± 0.44
Ammonia nitrogen (mg/L)	0.03–0.25	0.05 ± 0.21	0.12 ± 0.008	0.17 ± 0.005
Nitrite nitrogen (mg/L)	0.016–0.056	0.10 ± 0.03	0.14 ± 0.10	0.31 ± 0.13
Nitrate nitrogen (mg/L)	0.09–0.48	0.23 ± 0.01	0.28 ± 0.00	0.36 ± 0.01

TABLE 3 Physico-chemical parameters of soil during the experimental period of 90 days

Parameters	Range	T1 (30/m^2)	T2 (45/m^2)	T3 (60/m^2)
Organic carbon (%)	0.75–1.3	1.07 ± 0.015	1.07 ± 0.018	1.10 ± 0.017
Soil pH	7.4–8.5	7.92 ± 0.09	8.00 ± 0.14	7.81 ± 0.12
Organic matter (%)	1.2–2.25	1.84 ± 0.03	1.85 ± 0.03	1.89 ± 0.03
Soil phosphorous (mg/100 g)	5.8–6.4	6.14 ± 0.03	6.27 ± 0.02	6.20 ± 0.01
Soil nitrogen (mg/100 g)	80–120	107.79 ± 0.14	107.96 ± 0.31	108.58 ± 0.25
Water retention capacity (%)	40–46	44.82 ± 0.43	42.8 ± 0.59	44.72 ± 0.61

TABLE 4 Water budgeting parameters include both inflows and outflows estimated during the experiment

Parameters	T1 (30/m^2)	T2 (45/m^2)	T3 (60/m^2)
First filling (m^3)	1100.00 ± 0.00	1100.00 ± 0.00	1100.00 ± 0.00
Rainfall (m^3)	5.2 ± 0.00	5.2 ± 0.00	5.2 ± 0.00
Surface runoff (m^3)	0.5 ± 0.00	0.5 ± 0.00	0.5 ± 0.00
Evaporation (m^3)	369.60 ± 4.83	370.40 ± 6.66	369.73 ± 5.47
Seepage (m^3)	629.40 ± 6.63	634.60 ± 8.79	628.93 ± 2.94
Consumptive water use index (m^3/kg)	7.41 ± 0.04	6.53 ± 0.07	6.74 ± 0.08
Total water use (m^3)	2093.33 ± 6.66	2099.30 ± 3.33	2092.96 ± 5.77

3.3 | Growth and survival under various stocking densities

The growth parameters of *P. vannamei* in different stocking densities showed varying trends throughout the culture period. The various growth parameters of *P. vannamei* recorded during the experimental period are average body weight, weight gain, percentage weight gain, specific growth rate, feed conversion ratio, feed efficiency ratio and percentage survival. The average body weight of *P. vannamei* was recorded at an interval of 11 days during the experimental period of 90 days, and the values are presented in Figure 2. The growth parameters are tabulated in Table 5. The average body weight of *P. vannamei* was observed and recorded at an interval of 15 days during the experimental period of 90 days. The highest body weight was observed in T1 (12.10 ± 0.12 g) with a low stocking density of 30/m^2, and the lowest body weight was observed in T3 (7.80 ± 0.12 g) with the highest stocking density of 60/m^2. There was a significant difference ($p < 0.05$) in the average body weight of shrimps cultured in T1, T2 and T3 treatments. In the case of survival of *P. vannamei* in the different experimental ponds, the highest and lowest survival rates were recorded in T1 and T3 treatments respectively. There was a significant difference ($p < 0.05$) among the different treatments T1, T2 and T3.

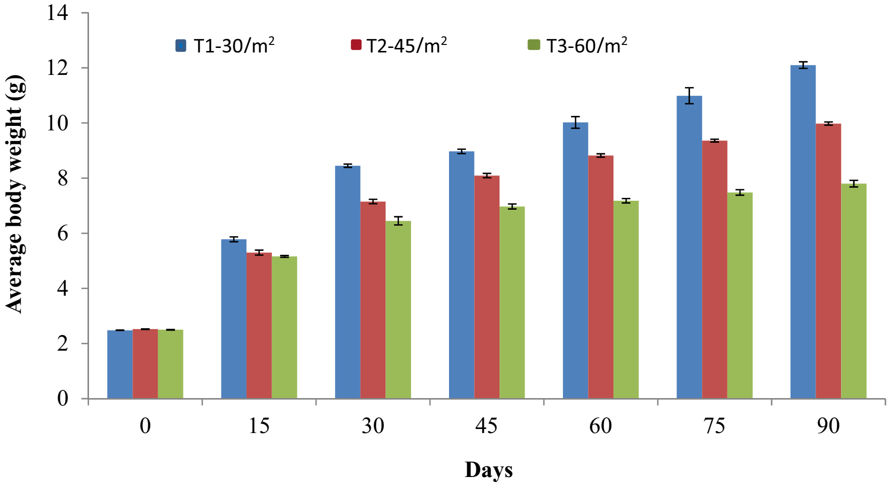

FIGURE 2 Average body weight (g) of *Penaeus vannamei* at different stocking densities during the experimental period of 90 days

TABLE 5 Growth parameters of *Penaeus vannamei* harvested from various treatments at the end of 90 days

Parameters	T1 (30/m^2)	T2 (45/m^2)	T3 (60/m^2)
Initial average body weight (g)	2.48 ± 0.01	2.52 ± 0.01	2.50 ± 0.01
Final average body weight (g)	12.10 ± 0.12^a	9.98 ± 0.06^b	7.80 ± 0.12^c
Survival (%)	80.49 ± 0.61^a	72.06 ± 0.74^b	68.70 ± 1.45^b
Weight gain (%)	382.78 ± 6.70^a	299.86 ± 0.82^b	211.98 ± 3.59^c
FCR	1.18 ± 0.03^c	1.42 ± 0.02^b	1.64 ± 0.03^a
SGR	1.75 ± 0.02^a	1.54 ± 0.00^b	1.26 ± 0.01^c
FER	0.85 ± 0.02^a	0.71 ± 0.01^b	0.61 ± 0.01^c
Biomass harvested (kg)	283 ± 1.53^c	322 ± 3.46^a	311 ± 3.79^b
Consumptive water use index (m^3/kg)	7.41 ± 0.04^a	6.53 ± 0.07^c	6.74 ± 0.08^b
Water productivity (kg/m^3)	0.135 ± 0.001^c	0.153 ± 0.002^a	0.148 ± 0.002^b

Note: All values in the same row with different superscripts differ significantly ($p < 0.05$) for each parameter.

4 | DISCUSSION

4.1 | Water and soil quality parameters under different stocking densities

Temperature is the most crucial parameter that influences the growth rate of penaeid shrimp (Tsuzum et al., 2007). The optimum growth and survival of shrimp are achieved by maintaining good quality water in culture ponds (Parvathi & Padmavathi, 2018). Since the last phase of the experiment was conducted in the winter, the water temperature fluctuated throughout the culture period of 90 days. In the beginning of the experiment, the temperature was found to be 29°C which was within the optimum range for *vannamei* juvenile culture. The temperature (29°C) was within the thermal preferendum for juvenile shrimps, which is 27–30°C (Ponce-Palafox et al., 1997). However, towards the end of the culture period, as the winter season commenced, the water temperature gradually decreased and was found to be 15°C. The thermal tolerance limit of *L. vannamei* is between 15 and 33°C with the best growth achieved in the range of 23–30°C (Rosenberry, 2003).

Dissolved oxygen concentration remained high throughout the culture. A minimum dissolved oxygen content of 3 ppm is required for the most warm water species, and 5 ppm is required for ideal growth and maintenance (Yaro et al., 2005). However, in the present study, the DO level did not drop below 4 ppm as it was an open pond environment with sufficient aeration. In shrimp farming, salinity of water is very important. In the present study, the salinity of water was found to be in the range of 12–14 ppt. A salinity range of 10–35 ppt was found to be ideal and recommended for shrimp culture by Karthikeyan (1994) and Gunalan et al. (2010). *L. vannamei* is a euryhaline species, and hence, it can tolerate a wide range of salinity (Atwood et al., 2003).

The pH of water plays a key role in growth and survival of shrimp. In the present study, the pH of water was found to be in the range of 8.1–8.6. Many authors have reported that a pH range of 7.6–8.6 was favourable for better growth and survival of *L. Vannamei* (Wang et al., 2004). Optimum concentrations of alkalinity and hardness facilitate shedding and proper formation of the exoskeleton and enhance the growth and survival of shrimps. Total alkalinity and hardness concentrations were found to be within the optimum range throughout the culture period. Lakra et al. (2014) reported an alkalinity range of 200–230 ppm and a hardness range of 3200–3700 ppm as optimum for the culture of *P. vannamei* in earthen ponds using inland saline groundwater. The concentrations of ammonia, nitrite and nitrate were found to be high in grow-out ponds having higher stocking density due to increased level of metabolites and unutilized feed. The values of ammonia, nitrite and nitrate were 70.58%, 67.70% and 36.10%, respectively, higher in grow-out ponds having the highest stocking density (60/m^2) as compared to those with the lowest stocking density (30/m^2). Potassium is the most crucial element in inland saline shrimp culture. In the present study, the potassium values were in the range of 20–70 ppm with reference to salinities in the pond water. The potassium concentration in inland saline groundwater was very low as compared to the natural seawater based on their salinities. High level of calcium and variable levels of magnesium in inland saline groundwater are important to maintain the desired ratio of calcium and magnesium ions (Lakra et al., 2014). Therefore, the potassium level was maintained during the culture period by manipulating required quantity of muriate of potash (KCL). Overall, in the present study, no significant difference in various water quality parameters was observed among the different treatments.

Pond bottom soil plays a major role in shrimp farming. The pond bottom soil with optimum organic carbon content and other nutrients promotes soil productivity. The various soil quality parameters such as soil pH, organic carbon (%), organic matter (%), total nitrogen (mg/100 g) and phosphorous (mg/100 g) were analysed. The interaction between the pond water and pond bottom soil has a great impact on water quality (Boyd, 1995). The soil pH was found to be within the range of 7.4–8.5.

Boyd (1995) reported that the optimal pH for pond soil is neutral. Organic carbon was initially estimated to be 0.75%, but it gradually increased to around 1.3% by the end of the culture period. This is due to increased amount of inputs and metabolites of animals that ends up in the sediment at the end of the experiment. Mohanty, Kumar, et al. (2014) reported enhanced organic carbon content later during the culture period. Boyd et al. (2002) reported an organic carbon concentration in the range of 1.0 to 3.0% (mineral soil and moderate organic matter content) in pond bottom soil of aquacultural ponds. Soil phosphorous and soil nitrogen were found to be in the range of 5.8–6.4 and 80–120 mg/100 g, respectively, for 0.1 ha pond area. Lakra et al. (2014) reported the nitrogen and phosphorous levels of 81.30 and 6.10 mg/100 g, respectively, in *P. vannamei* culture ponds with inland saline groundwater.

4.2 | Water budgeting under different stocking densities

In aquaculture, water used to make feed for animal production is very low compared with other terrestrial food production sectors, but the water requirement on fish farm can be up to 45 m^3/kg biomass produced in aquaculture ponds (Verdegem et al., 2006). In the present study, the water requirement for unit production of *P. vannamei* with different stocking densities in inland saline groundwater was estimated. The mean water requirement in T1 (30/m^2), T2 (45/m^2) and T3 (60/m^2) was 7.41 ± 0.04, 6.53 ± 0.07 and 6.74 ± 0.08 m^3/kg respectively. The water requirement in each treatment was significantly different ($p < 0.05$) from each other. Higher the production, lower was the requirement of water for unit production of *P. vannamei*. Sharma et al. (2013) estimated a water requirement of 10.3 m^3 to produce 1 kg of carp. Out of which, 7.6 m^3/Kg of fish produced was devoted towards the requirements of the culture system. They reported a water requirement of 2.7 m^3/kg production of fish. Mohanty et al. (2016) estimated the water requirement and consumptive water use in polyculture systems of carp and prawn under various management practices. In their study, 1 m^3 water was used to produce 141 g of carp biomass, while the same amount of water could produce 400 g of rice (Bouman et al., 2007). This indicates that the amount of water utilized in aquaculture is very high as compared to irrigated agriculture (Boyd & Gross, 2000). Adhikari et al. (2017) estimated the quantity of water used for carp culture in three different states of India viz., Orissa, Andhra Pradesh and West Bengal. The evaporation and seepage rates were significantly different among the fish ponds of these three states of India. The consumptive water use was 3.34 ± 0.47, 3.35 ± 0.36 and 2.67 ± 0.23 m^3/kg in Orissa, West Bengal and Andhra Pradesh respectively.

The loss of water in aquaculture ponds due to evaporation is a result of climatic conditions. In the present study, the mean evaporation rate in three treatments T1, T2 and T3 was 369.60 ± 4.83, 370.40 ± 6.66 and 369.73 ± 5.47 mm respectively. The mean seepage rate in three treatments T1, T2 and T3 during the experiment was 629.40 ± 6.63, 634.60 ± 8.79 and 628.93 ± 2.94 mm respectively. Mohanty, Mishra, and Patil (2014) reported an average evaporation loss of 4.92 mm/day. Daily seepage loss recorded was in the range of 0.14 to 0.24 cm/day with an average of 0.19 ± 0.04 cm/day over a period of 1 year in Orissa. In the present study; owing to the high water temperature in the first month of the culture period, the daily mean evaporation rate was high, which was gradually decreased towards the end of the experiment as the temperature dropped due to the winter season. The seepage rate was high in the experimental ponds due to the low clay content in the bottom soil. The study area received rainfall thrice during the culture period of 90 days. The total rainfall was 5.2 mm throughout the culture period. Many authors have reported that the intensity of rainfall varied according to the climatic conditions. Verma, Jacob, & Prakash, 2010 reported no rainfall in the area during the experimental period. Therefore, the present study fulfils the hydrological equation formulated by Winter (1981) and Boyd (1985).

4.3 | Growth and survival under various stocking densities

Growth is defined as weight/length increment in an animal which is influenced by the culture conditions (Boyd & Tucker, 2012) viz., stocking density and water quality and nutritional inputs (Halver, 2003) such as feed and growth supplements. The present study exhibited the significant influence of varying stocking densities on the growth and survival of *P. vannamei*. The final body weight and the growth rate of *P. vannamei* was found to be higher in T1 (30/m^2) and T2 (45/m^2) and lowest in T3 (60/m^2). Similarly, the total biomass was also significantly affected ($p < 0.05$) by varying stocking density; the highest biomass of 322.00 ± 3.46 kg was recorded in T2 (45/m^2) followed by 311 ± 3.79 kg in T3 (60/m^2), whereas the lowest biomass was observed in T1 (30/m^2) with a value of 283.00 ± 1.53 kg. The results are in agreement with previous studies (Araneda et al., 2008; Maguire & Leedow, 1983). Varying stocking density significantly affected the survival of *P. vannamei*. The highest and the lowest survival rates were recorded in T1 and T3 respectively. Similar results were reported in *P. vannamei* (Gao et al., 2017; Suriya et al., 2016). Previous reports have proven that lower stocking density results in better growth performance and production. This may be attributed to the improved stress resistance (Gao et al., 2017), increased feed utilization, antioxidant ability (Liu et al., 2017) and growth gene expression.

5 | CONCLUSION

Aquaculture will be sustainable only when it is socially acceptable, economically feasible and environmentally friendly. Water budgeting plays a vital role in enhancing the production and water productivity, and reducing aquaculture's impact on the environment by efficient water usage. From this study, it is observed that the consumptive water use index was significantly less in T2 (6.53 ± 0.07 m^3/kg) followed by T3 (6.74 ± 0.08) and T1 (7.41 ± 0.04 m^3/kg), and the water productivity of *P. vannamei* was significantly higher in T2 (0.153 ± 0.002 kg/m^3) followed by T3 and T1. Considering the total quantity of water used and the quantum of shrimp produced from the earthen grow-out ponds using inland saline groundwater, a stocking density of 45/m^2 and a water budget of 6.53 m^3/kg production of shrimp could be recommended as optimum.

AUTHOR CONTRIBUTIONS

A. Pattusamy designed the study and contributed to the data collection, analysis and draft writing. M.H. Chandrakant involved in conceptualization, design, supervision, draft writing and editing. N.K. Chadha involved in conceptualization and supervision, and revised the manuscript. P.B. Sawant contributed to methodology and draft writing. H. Krishna designed the experiments and analysis. A.K. Verma involved in analysis, draft writing and editing.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The authors confirm that the data generated during the present study are included in the manuscript.

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