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Research Article

ENHANCEMENT OF SOIL QUALITY USING BETTER MANAGEMENT PRACTICES (BMPs) IN *LITOPENAEUS VANNAMEI* CULTURED GROW-OUT PONDS WITH SPECIAL REFERENCE TO SEASONAL VARIATION

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ABSTRACT
Indian fisheries and aquaculture constitute a vital role of the national's food production system, contributing significantly to nutritional security, employment opportunities and export. Furthermore, shrimp culture remains the backbone of India's seafood export industry particularly *Litopenaeus vannamei*. The production is predominately concentrated in the coastal states of India where environmental conditions favor brackish-water culture systems. Within these systems, seasonal fluctuations in water parameters, rainfall and nutrient influx exert a strong influence on pond ecology, water-soil interactions and overall pond productivity. However, in aquaculture activities over the years the water quality management has given more attention than compared to pond soil quality. Due to this inadequate management of soil quality many farms continue to experience recurrent disease outbreaks, undetected degradation, poor survival rates, growth performance, which results in reduction of both yield and profitability. So to mitigate these problems the present study had been undertaken to enhance the soil quality using Better Management Practices (BMPs) in *L. vannamei* cultured grow-out ponds, located in Alluru village, Prakasam dist. Andhra Pradesh, during the pre and post- monsoon seasons. Key soil parameters such as texture, moisture, bulk density, water holding capacity (WHC), pH, electrical conductivity (EC); organic carbon, calcium carbonate ($CaCO_3$), available nitrogen, available phosphorus, total nitrogen, total phosphorus and potassium (K) were maintained under BMP guidelines. Results showed that the adoption of BMPs maintained soil parameters in optimal ranges during pre-monsoon and post-monsoon. The mean results during pre-monsoon were: moisture (14.32), bulk density (1.35), WHC (33.28), pH (7.21), EC (5.00); organic carbon (1.73), $CaCO_3$ (7.2), available-N (57.88), available-P (4.76), total-N (224.61), total-P (21.45) and K (24.70). The mean results during post-monsoon: moisture (18.72), bulk density (1.34), WHC (38.08), pH (7.00), EC (3.90), organic carbon (1.61), $CaCO_3$ (5.94), available-N (52.67 ± 0.69), available-P (4.22), total-N (204.40), total-P (19.04) and K (23.75). The outcome of the study highlights BMPs effectiveness in maintaining soil parameters within the standard ranges during both seasons.

Keywords: *Better Management Practices (BMPs), Litopenaeus vannamei, shrimp culture, soil parameters, seasonal variation*

INTRODUCTION
Indian fisheries and aquaculture constitute a vital role of the national's food production system, contributing significantly to nutritional security, employment opportunities and export revenue. In FY 2022-23, India contributed about 8% to global fish production, with an estimated 18.43 MT production

(FAO, 2024; DoF, 2023). Of this aquaculture sector accounts more than half, reflecting the growing importance of inland and coastal farming systems.

The fisheries sector contributes approximately 1.24% to India's national GDP and 7.07% to agricultural GDP (DoF, 2023; NFDB, 2023). The sector provides livelihood support to nearly 16 million people, both directly and indirectly, through various activities such as production, processing, transportation and marketing (NFDB, 2023; DAHD, 2024). India is also a major player in global seafood trade, with marine and aquaculture exports reaching US$ 8.09 billion in FY 2022-23, of which farmed shrimp contributed nearly 70% (MPEDA, 2023).

Shrimp aquaculture remains the backbone of India's seafood export industry and it is more profitable sector than agriculture due to its short production cycle (Ratti & Kunda, 2025b). Production is predominately concentrated in the coastal states of Andhra Pradesh, Gujarat, Tamil Nadu, Odisha, West Bengal, Karnataka, Maharashtra and Goa, where environmental conditions favor brackish-water culture systems (DoF, 2023; MPEDA, 2023). These states collectively support large-scale farming of *L. vannamei*, which has driven India's rapid growth in export-oriented aquaculture (FAO, 2024; MPEDA, 2023). In India, the coastal areas are productive and rich in natural resources. India has 1.24 million ha of brackish water area, spread over coastal states and Union territories (CAA, 2024). Within these systems, seasonal fluctuations in water parameters, rainfall and nutrient influx exert a strong influence on pond ecology, water-soil interactions and overall pond productivity.

In aquaculture activities over the years the water quality management has given more attention than compared to pond soil quality (Bansode *et al*., 2020; Prihutomo *et al*., 2016). Soil serves as a nutrient reservoir, chemical buffer, and biological filter, regulating pH, nutrient availability adsorbing organic remains of feed, fecal excrements, and algal products (Chakraborty *et al*., 2017; Hasibuan *et al*., 2023). The physical, chemical and biological characteristics of pond water are strongly influenced by pond sediment which pond bottom soil acts as storehouse for many substances accumulated in pond ecosystem (Boyd, 1995). Both sediment and soil quality are among the most significant factors determining an aquaculture enterprise's productivity and sustainability (Carvalho *et al*., 2024; Prihutomo *et al*., 2016).

Sediment acts as both a sink and source of nutrients such as nitrogen and phosphorus, when poorly managed, can lead to eutrophication and oxygen depletion (Patel and Pandit, 2025). They affect water chemistry and quality, nutrient cycling, and the health of aquatic life forms (Boyd & Tucker. 1998). Due to this inadequate management of soil quality many farms continue to experience recurrent disease outbreaks, undetected degradation, poor survival rates, growth performance, which results in reduction of both yield and profitability (Bansode *et al*., 2020; Boyd & Thunjai, 2002; Patel and Pandit, 2025).

To mitigate these challenges, the adoption of standardized Better Management Practices (BMPs) has been shown to improve pond productivity and resilience. BMPs include pond preparation; liming, controlled fertilization, sediment removal and organic load reduction which improves the soil quality (Boyd, 2003; Boyd & Thunjai, 2002; Corsin *et al*., 2008; Muthu & Sathiyamurthy, 2025; Ratti & Kunda, 2025a). Therefore, this study was undertaken to evaluate the soil quality enhancement in *L.vannamei* grow-out ponds through implementation of BMPs, with special emphasis on seasonal variation across pre monsoon and post-monsoon seasons.

MATERIALS AND METHODS

Experiment site

The present study is undertaken during (2024-25) in Pre- monsoon (February – May) and Post-monsoon (September – December) seasons, for this experiment four cultured grow-out ponds were taken, located at Alluru village, Prakasam district, Andhra Pradesh, India.

Better Management Practices (BMPs)

Better Management Practices (BMPs) were implemented in these ponds during pre and post-monsoon seasons as recommended by MPEDA (2023), Boyd (2003) and (Government of India (2024).

Pond Preparation and Management Practices

After complete harvest, draining of the pond (fig.1) was carried out to remove the sludge present in the pond bottom. Before refilling, pond bottom depth was increased and maintained between 1.2 – 1.5 meter at the middle of the pond to increase water holding capacity. Regular checking of pond bottom soil during culture period was carried out to detect if there is any presence of black soil or foul smell. Chain dragging was carried out at feeding areas at regular intervals to oxidize the organic matter.

Drying and Tilling

All the ponds were allowed to dry between crops. Sun drying was carried out for nearly 30 days until the soil gets cracked. After complete drying, the soil surface was subjected to Ploughing and tilling. It was done two times with the gap of four days to remove the entrapped toxic gases and for enhancement of fertility of the pond bottom. After ploughing the pond bottom condensed to reduce the turbidity and seepage rate.

Liming and Disinfection

After filling the pond, disinfection with bleaching powder ($CaOCl_3$) at the rate of 400 kg ha $^{-1}$ was carried out as a part of the biosecurity measures. Soil pH was tested and lime was added based on the soil pH described by MPEDA (2023). Lime ($CaCO_3$) was spread uniformly all over the pond bottom, 7 days after bleaching application to all ponds at the rate of 200 kg ha^{-1}. It is used to nullify the acidity of the soil and to increase overall alkalinity and hardness concentration that enhances primary productivity.

Fertilization

Once the pond bottom has dried and necessary soil treatments applied, the ponds were refilled with water within 4 days from nearby estuarine canal and top-up using motor pumps. Organic fertilizers like vermicompost 400 kg ha^{-1} were spread uniformly all over the pond bottom before filling with water. After a week, algal boom develops. Then fermented mixture of rice bran, jaggery and quality brewer's yeast (100:40:1 kg ha^{-1}) were applied in doses for three days during the morning period and spread all over the ponds. Seed stocking was carried out when pond water colour develops into green. Liming and Fertilization was carried out at an interval of 7 and 15 days during the whole culture period.

Sample Collection and frequency

Soil samples were collected throughout the cultured period. From each pond, soil samples from the bottom was taken at 0–10 cm depth using a soil sampler (a PVC tube of 5 cm diameter and length of 3 m) were collected from the four corners and the centre of the pond. A total of 1 kg soil samples were taken from each cultured grow-out pond, all these soil samples were mixed to form the composite sample of the respective ponds and packed in properly labeled zip covers. The samples were dried in the shade and ground to powder. The powdered soil sample is air dried, sieved through a 2mm sieve and finally through 80µ mesh sieve. The fine soil samples were then divided into two parts for analysis of the physico-chemical quality parameters and essential nutrient contents such as carbon, nitrogen, phosphorus and potassium, respectively.

Sample Analysis

The soil samples collected from cultured grow-out ponds are further analyzed by following methods:

Soil texture is estimated by (Corral-pazos-de-Provens *et al*., 2022). Moisture of soil samples were estimated using standard gravimetric method described by Black (1965). Bulk density analysis, carried out by the procedure described by (Boyd, 1995). Water holding capacity is determined by Keen's box method of Piper (1966). pH was estimated by 1:2.5 soil water suspension using digital pH meter stated by Jackson (1973). The same soil-water suspension was used to determine Electrical conductivity by conductivity meter stated by Piper (1966). The organic carbon was determined by Walkley & Black (1934) method. Calcium Carbonate was determined by rapid titration technique described by Piper (1966). The available nitrogen content of soil samples were determined by following method of Subbiah & Asija (1956). The available phosphorus of soil samples were determined by following method of Olsen (1954). Total nitrogen was analyzed using dry combustion method stated by Wright & Bailey, (2001). Total phosphorus was determined with the Bray-1 (HCl 0.025 N +NH4F 0.03 N) (extraction method), and the Olsen (NaHCO3 0.50 N; pH 8.5) fraction technique. Potassium in the soils was extracted by using neutral normal Ammonium acetate and estimated by aspirating the extract into the flame photometer technique by Jackson (1973).

Statistical analysis

All quantitative data obtained from the cultured grow-out ponds were expressed as mean ± Standard Deviation (SD); n=4. ANOVA was performed to analyze significant differences in the value of different parameters to compare both Seasons. Statistical significance was taken into consideration at $p < 0.05$. Effect sizes were calculated to assess the magnitude of differences.

a) pond draining b) drying and tilling

c) liming and disinfection d) fertilization and refilling of the pond

Fig.1. Images of pond preparation and management practices

RESULTS AND DISCUSSION

The implementation of Better Management Practices (BMPs) provided clear and statistically strong changes in soil properties during both seasons and four cultured grow-out ponds (Table 1). Season emerged as the dominant source of variation: 11 of the 12 measured parameters showed highly significant pre- vs post-monsoon differences ($p < 0.001$), while only bulk density remained statistically unchanged ($F = 1.66$, $p = 0.202$). One-way ANOVA for the season effect confirmed strong monsoon-driven shifts in soil moisture ($F = 1266.75$, $p < 0.001$), WHC ($F = 317.70$, $p < 0.001$), soil pH ($F = 81.49$, $p < 0.001$), EC ($F = 837.98$, $p < 0.001$), organic C ($F = 98.13$, $p < 0.001$), $CaCO_3$ ($F = 59.56$, $p < 0.001$), available N ($F = 162.86$, $p < 0.001$), available P ($F = 105.62$, $p < 0.001$), total N ($F = 162.88$, $p < 0.001$), total P ($F = 105.79$, $p < 0.001$) and K ($F = 14.67$, $p < 0.001$).

The physico-chemical properties of pond soil acts as a vital factor, which determines the pond productivity due to its functional role in controlling the pond stability. The parameters such as pH, $CaCO_3$, and salinity influence microbial activities, nutrient cycling and water quality (Boyd, 1955; Prihutomo *et al*., 2016). In addition, the pond fertilizers depends upon the amount of primary and secondary nutrients such as N, P, K and C which are already present in the soil bottom (Boyd, 2003).

Consistent soil management practices such as soil testing, liming, controlled fertilization and prevention of excess organic matter can significantly enhance aquaculture sustainability (Manam, 2025). The sampling of soil should carry out at regular intervals of culture periods to determine the available nutrient status, which helps in determining cost-effective management (Haritha *et al*., 2024; Tenedero & Surtida, 1986).

Table 1: Seasonal variation in soil parameters, of *Litopenaeus vannamei*: statistical comparison of pre- and post-monsoon periods

Parameters		Pre-Monsoon	Post-Monsoon	Change (%)	F (Season)	p (Season)	Standard Range	Standard Reference
Physical Parameters								
Soil Texture		Clay Loam	Clay Loam			-		
Soil Moisture (%)	Mean	14.32 ± 0.43	18.72 ± 0.53	+30.65	1266.75	<0.001***	10-20	(Li.L. *et al*., 2015)
	Range	13.71 - 14.42	18.11 - 19.39					
Bulk Density (g cm^{-3})	Mean	1.35 ± 0.02	1.34 ± 0.02	-0.75	1.66	0.202 ns	1.0–2.0	(Boyd, 1995)
	Range	1.32 - 1.39	1.31 - 1.37					
WHC (%)	Mean	33.28 ± 1.14	38.08 ± 0.77	+15.02	317.70	<0.001***	35-70	(CIBA, 2019)
	Range	31.82 - 34.99	37.07 - 38.85					
Chemical Parameters								
Soil pH	Mean	7.21 ± 0.12	7.00 ± 0.18	-3.51	81.49	<0.001***	6.5–7.5	(Balasubramanian *et al*., 2021)
	Range	7.09 - 7.39	6.83 - 7.04					
EC (dS m^{-1})	Mean	5.00 ± 0.20	3.90 ± 0.06	-21.96	837.98	<0.001***	>4	(Balasubramanian *et al*., 2021)
	Range	4.78 - 5.25	3.85 - 3.99					
Organic Carbon (%)	Mean	1.73 ± 0.04	1.61 ± 0.04	-6.40	98.13	<0.001***	1.5–2.0	(Balasubramanian *et al*., 2021)
	Range	1.69-1.80	1.57-1.66					
$CaCO_3$ (%)	Mean	7.2 ± 0.75	5.94 ± 0.79	-17.37	59.56	<0.001***	>5.0	(Balasubramanian *et al*., 2021)
	Range	6.3 - 8.0	4.97 - 6.73					

Available Nutrients								
Available –N (mg 100 g^{-1})	Mean	57.88 ± 1.82	52.67 ± 0.69	-8.99	162.86	<0.001***	50-70	(Balasubramanian *et al*., 2021)
	Range	55.49 - 59.69	51.97 - 53.42					
Available-P (mg 100 g^{-1})	Mean	4.76 ± 0.26	4.22 ± 0.17	-11.22	105.62	<0.001***	4-6	(Balasubramanian *et al*., 2021)
	Range	4.44 - 5.09	3.99 - 4.41					
Total Nutrients								
Total-N (mg 100 g^{-1})	Mean	224.61± 7.06	204.40 ± 2.68	-8.99	162.88	<0.001***	140-250	(Boyd, 1995)
	Range	215.33 - 231.62	201.67 - 207.30					
Total-P (mg 100 g^{-1})	Mean	21.45 ± 1.18	19.04 ± 0.79	-11.23	105.79	<0.001***	15-40	(Boyd & Musig, 1992)
	Range	20.01 - 22.90	17.97 - 19.87					
Micro Nutrients								
K (mg 100 g^{-1})	Mean	24.70 ± 1.16	23.75 ± 1.18	-3.85	14.67	<0.001***	10-25	(CIBA, 2019)
	Range	23.19 - 25.84	22.03 - 24.66					

All values are expressed as Mean ± Standard Deviation (SD); n=4 (number of ponds/season)
F and p correspond to one-way ANOVA for the season effect (pre vs post-monsoon seasons).
*Significance: *** p < 0.001; ** p < 0.01; * p < 0.05; ns: indicates not significant p ≥ 0.05*
WHC: Water Holding Capacity; EC: Electrical Conductivity; N: Nitrogen; P: Phosphorus; $CaCO_3$: Calcium Carbonate. K: Potassium

Physical parameters

Soil Texture

The type of soil present in study area is clay-loam type (Table 1). As the texture and composition of bottom soil plays a vital role in maintaining soil productivity and it considered as third most important factor in site selection in aquaculture. Differences in soil texture can influence the nutrients and thereby affects on overall growth (Bhowmick *et al*., 2024). According to McCarthy (2007) soils with 5-10% clay and a well grades particle size distribution are preferable to clays for earthwork construction, and more convenient for pond drying and tilling between crops (Boyd, 1995).

Soil Moisture

From table 1 and fig 2 we can observe soil moisture ($p < 0.001$) averaged 14.32 ± 0.43% to 18.72 ± 0.53%, a +30.65% change in pre and post-monsoon seasons, respectively. It ranges between 13.71 - 14.42% and 18.11 - 19.39%, across two seasons. The amount of water which is present in soil is termed as soil moisture, which plays a key role in water cycle and hydrology (Machireddy, 2025).

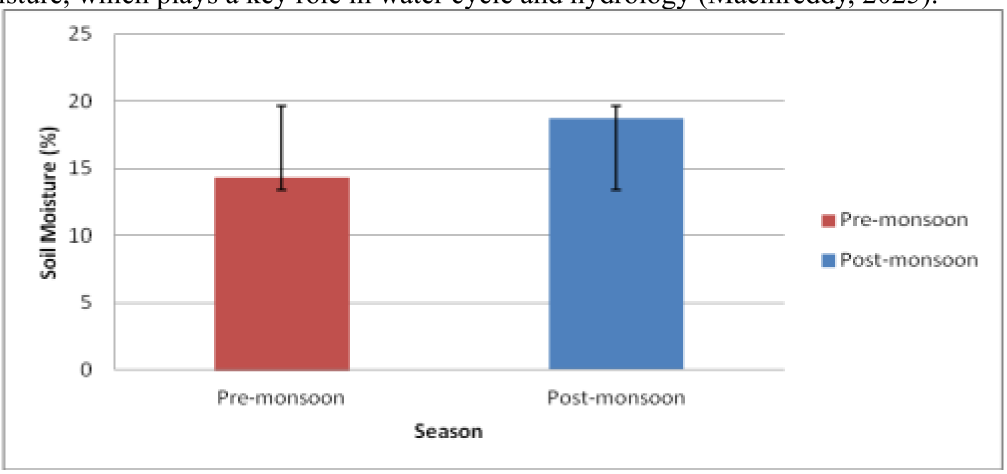

Fig. 2. Variation in soil moisture during pre and post-monsoon seasons

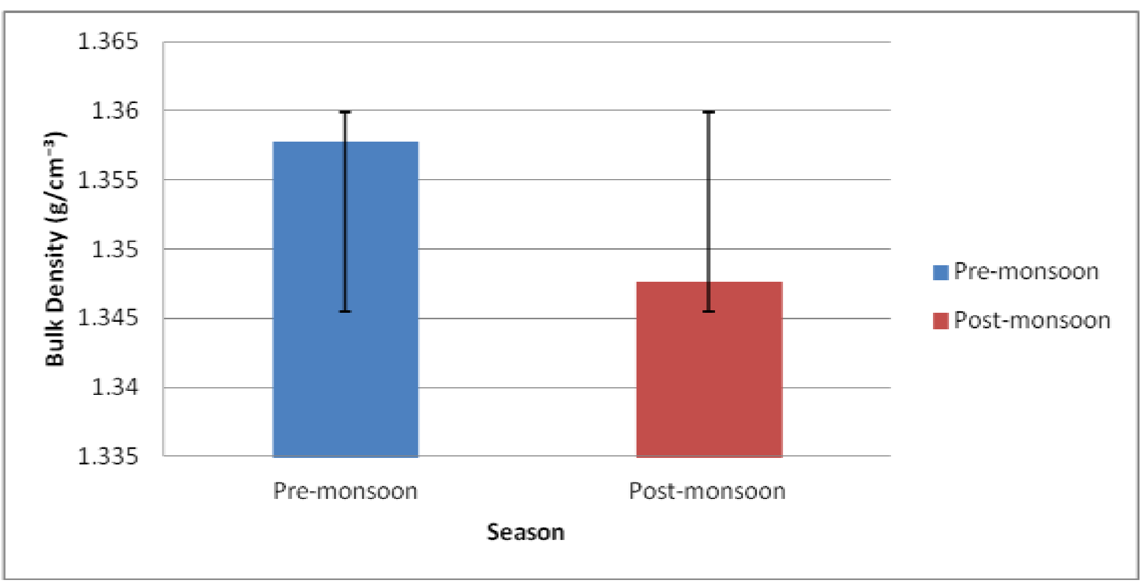

Fig. 3. Variation in bulk density during pre and post-monsoon seasons

Bulk Density

From table 1 and fig 3 we can observe bulk density shows slight variation, from 1.35 ± 0.02 g cm^{-3} (pre-monsoon) and 1.34 ± 0.02 g cm^{-3} (post-monsoon), consistent with its non significant season effect. It ranges between 1.32 - 1.39 g cm^{-3} and 1.31 - 1.37 g cm^{-3}, across two seasons.

Yuvanatemiaya & Boyd (2006) in their studies observed that, there is difference in bulk density values with sediment removal and without sediment removal. Similarly studies were showed by Prihutomo *et al*., (2016) that bulk density increases by removal of pond sediment.

Water Holding Capacity (WHC)

From table 1 and fig 4 we can observe WHC roses from 33.28 ± 1.14% (pre-monsoon) to 38.08 ± 0.77% (post-monsoon) (+15.02%), ranging between 31.82 - 34.99% and 37.07 - 38.85% across two seasons.

Boyd (1995) and Boyd & Tucker (1998) reported that pond sediments typically increase WHC during the monsoon due to higher pore-water content and restoration of soil aggregates. According to Lal, (1987) and (Hesse) 1971 tropical soil hydrology shows that WHC have a propensity to rise after heavy rainfall phases because finer sediment fractions and organic matter develop capillary porosity and water retention capacity.

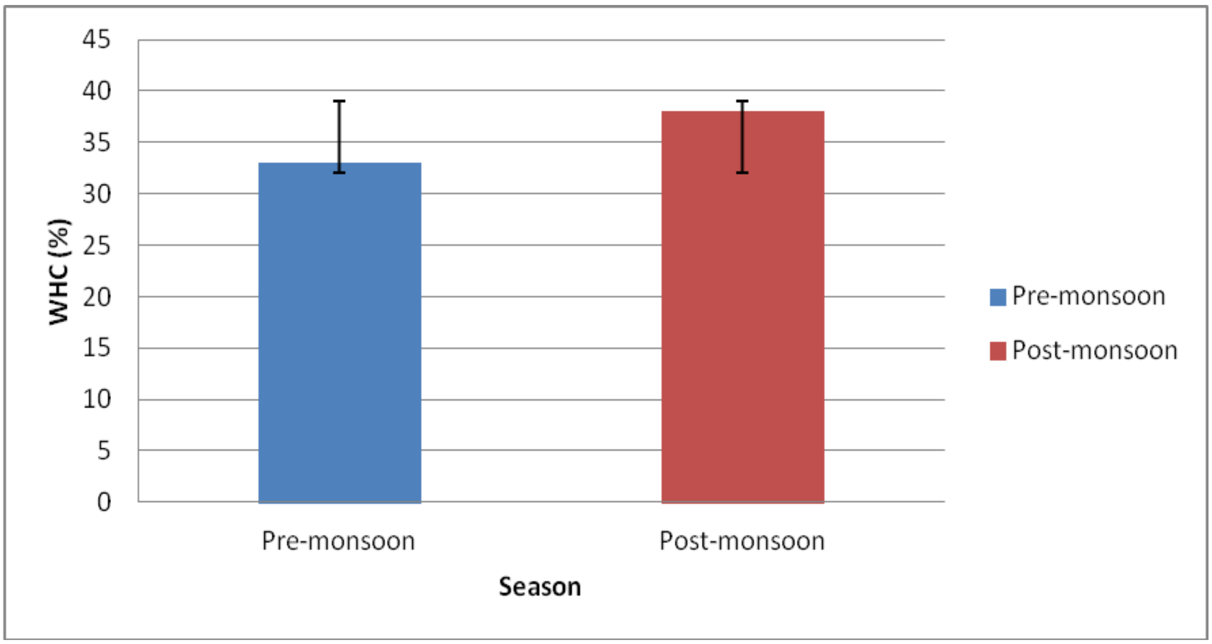

Fig. 4. Variation in Water Holding Capacity during pre and post-monsoon seasons

Chemical parameters

pH

From table 1 and fig 5 we can observe soil pH declined from 7.21 ± 0.12 (pre-monsoon) to 7.00 ± 0.18 (post-monsoon), ranging between 7.09 - 7.39 and 6.83 - 7.04 across two seasons.

Soil pH is the most important factor influencing pond productivity, chemical nature of the water column (Boyd & Tucker, 1998; Manam, 2025). The optimal pH (6.5-7.5) ensures the nutrients availability to plankton and aquatic species (Manam, 2025). It is influenced by the degree of base unsaturation of cation exchange sites, the presence or absence of carbonates (Boyd, 1995).

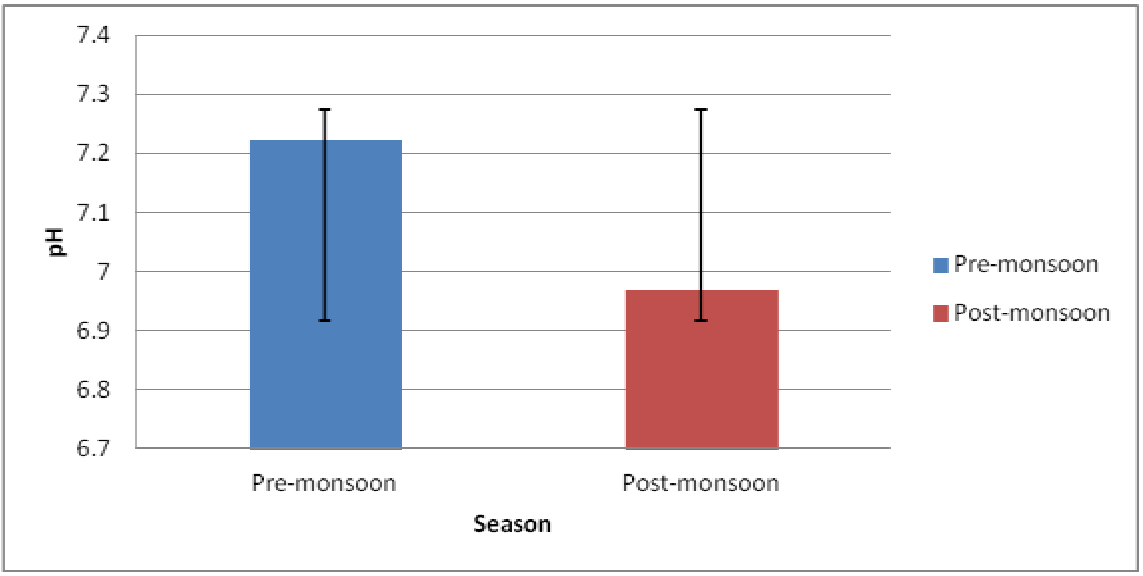

Fig. 5. Variation in pH during pre and post-monsoon seasons

Electrical Conductivity (EC)

EC is a measure of soil cation adsorption capacity (Ellis & Foth, 2018). From table 1 and fig 6 we can observe EC decreased from 5.00 ± 0.20 dS m^{-1} to 3.90 ± 0.06 dS m^{-1} (−21.96%) in pre-and post monsoon seasons respectively. It ranges between 4.78 - 5.25 dS m^{-1} and 3.85 - 3.99 dS m^{-1} across two seasons. Saraswathy *et al*., (2016) in her study recorded EC with 5 dS m^{-1}, and stated it is suitable for shrimp culture. Similar changes were documented by Boyd (1995) and Boyd & Tucker (1998), that monsoon flushing decreases the concentration of exchangeable ions and reduce pond sediment salinity.

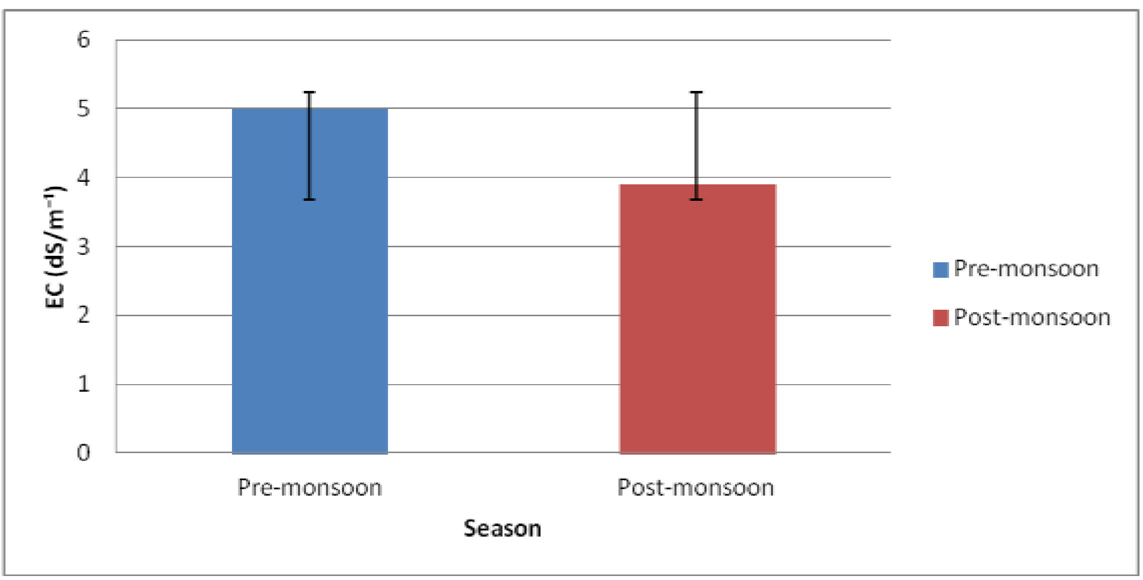

Fig. 6. Variation in Electrical Conductivity during pre and post-monsoon seasons

Organic Carbon (OC)

From table 1 and fig 7 we can observe organic carbon declined from 1.73 ± 0.04% to 1.61 ± 0.04% (−6.40%) in pre-and post monsoon seasons respectively. It ranges between 1.69 – 1.80 and 1.57 – 1.66

across two seasons. Rao et al. (2014) and Sarma et al. (2012) observed lower post-monsoon OC in estuarine and coastal sediments of India due to dilution with inorganic material and enhanced mineralization. In aquaculture perspective, Avnimelech (2015) and Boyd & Tucker (1998) reported that OC in shrimp ponds commonly falls within 1–3% and fluctuates seasonally depending on feed inputs, organic loading, and monsoon-driven sediment resuspension. Field studies in Indian aquaculture ponds have also shown significant seasonal variation in sediment OC, with pre-monsoon enrichment followed by post-monsoon reduction, consistent with the present findings (Ghosh et al., 2016; Kumar et al., 2019).

Organic carbon influences a variety of physico-chemical properties of pond bottom soils and release diverse nutrient elements that increase pond yield (Roy *et al*., 2023). It serves as a vital carbon source for bacterial flora in ponds. Xinglong & Boyd, (2006) suggested, organic carbon can be used as reliable marker of microbial activity. Low organic carbon influence bacterial and macrobenthic in pond (Shafi *et al*., 2021).

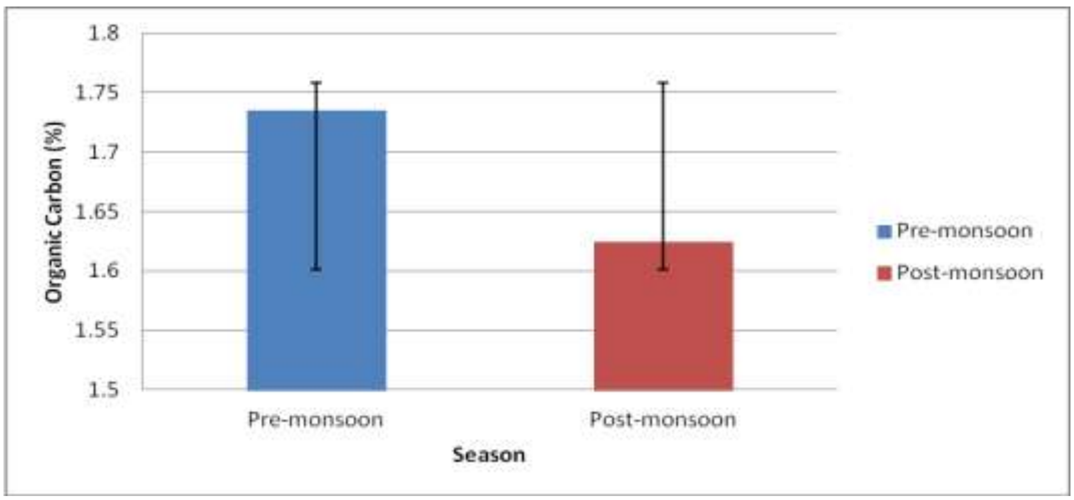

Fig. 7. Variation in Organic Carbon during pre and post-monsoon seasons

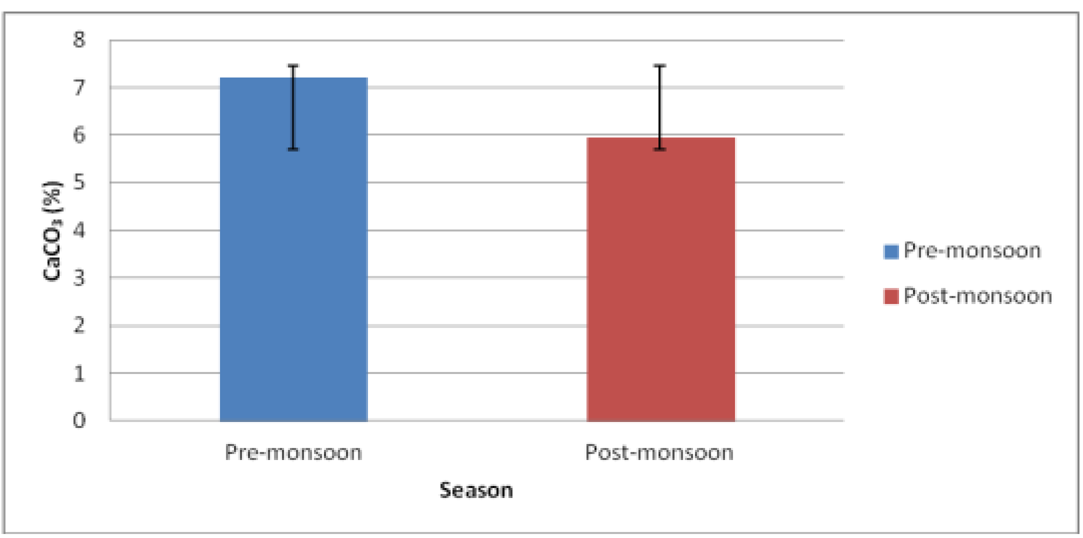

Fig. 8. Variation in $CaCO_3$ during pre and post-monsoon seasons

Calcium Carbonate ($CaCO_3$)

From table 1 and fig 8 we can observe $CaCO_3$ dropped from 7.20 ± 0.75% to 5.94 ± 0.79% (−17.37%) in pre-and post monsoon seasons respectively. It ranges between 6.3 – 8.0 and 4.97 – 6.73 across two seasons. Saraswathy *et al*., (2016) in her study recorded $CaCO_3$ content of the soils from Krishna and Guntur districts were 4.02 and 2.37% respectively.

$CaCO_3$ is another vital parameter which it acts as natural buffer, stabilizing pond water pH and increasing alkalinity. This buffering capacity prevents sudden pH fluctuations that may stress aquatic organisms. Furthermore, adequate levels of $CaCO_3$ promote microbial processes like nitrification, which are essential for the conversion of toxic ammonia into less harmful nitrate (Boyd, 2020).

Available Nitrogen

From table 1 and fig 9 we can observe available nitrogen decreased from 57.88 ± 1.82 to 52.67 ± 0.69 mg 100 g^{-1} in pre-and post monsoon seasons respectively. It ranges between 55.49 – 59.69 and 51.97 – 53.42 across two seasons. This decline reveals a characteristic seasonal change in tropical aquaculture pond sediments, where monsoon-persuade leaching, sediment interruption, and increased microbial activity can decrease nitrogen availability. Earlier studies have shown that heavy rainfall and runoff dilute ammoniacal and nitrate-N pools and improve denitrification and mineralization losses, resulting in lower available nitrogen after the monsoon period (Sarma et al., 2012; Rao et al., 2014).

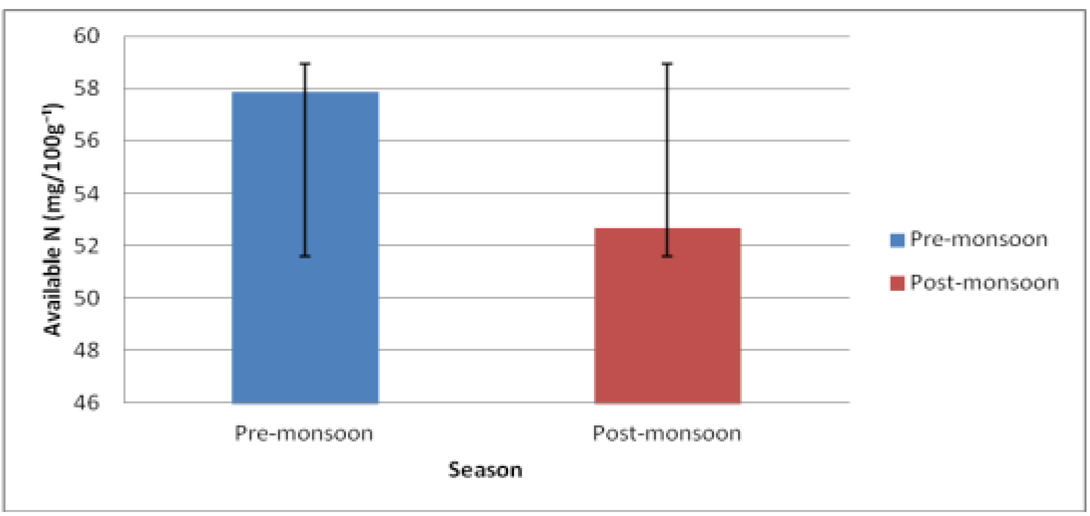

Fig. 9 Variation in Available-N during pre and post-monsoon seasons

Available Phosphorus

From table 1 and fig 10 we can observe available phosphorus fell from 4.76 ± 0.26 to 4.22 ± 0.17 mg 100 g^{-1} (−11.22%) in pre-and post monsoon seasons respectively. It ranges between 4.44 - 5.09 and 3.99 - 4.41 across two seasons. This reduction is consistent with typical monsoon-driven nutrient dynamics in tropical soils, where higher rainfall increases leaching losses, runoff, and exchange of labile phosphorus into less available forms. Similar seasonal declines in available-P have been documented in agricultural

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soils of Maharashtra, where Yadav et al. (2019) reported significant seasonal variation in soil chemical characteristics, including decreased levels in available nutrients from the monsoon period.

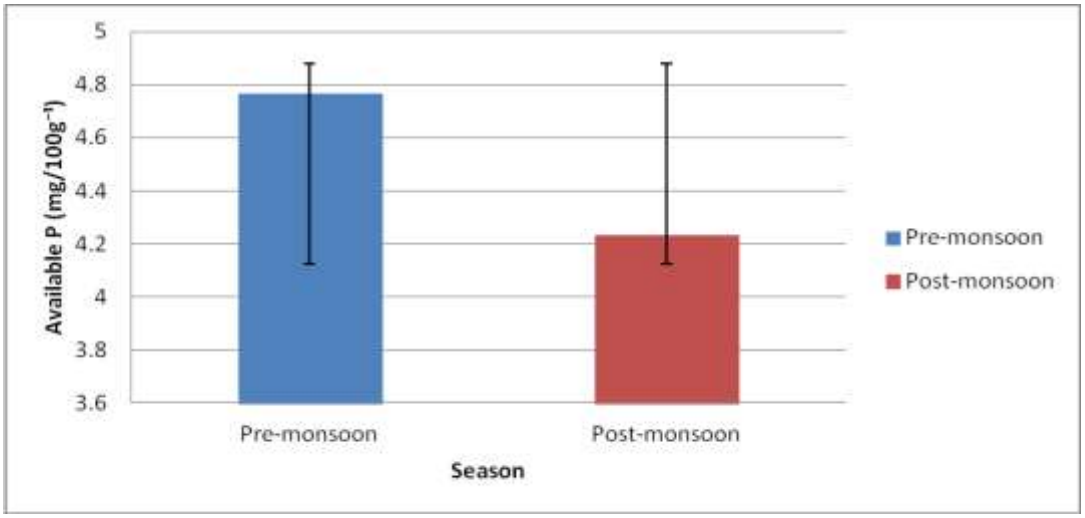

Fig. 10. Variation in Available-P during pre and post-monsoon seasons

Total Nitrogen
From table 1 and fig 11 we can observe available nitrogen decreased from 224.61 ± 7.06 to 204.40 ± 2.68 mg 100 g^{-1} in pre-and post monsoon seasons respectively. It ranges between 215.53 - 231.62 and 201.67 – 207.30 across two seasons.
Yuvanatemiya & Boyd (2006) in their studies observed that, there is difference in total-N values with sediment removal and without sediment removal. The low N levels inhibit the decomposition of organic matter at the pond bottom by aerobic bacteria (Hasibuan *et al*., 2023).

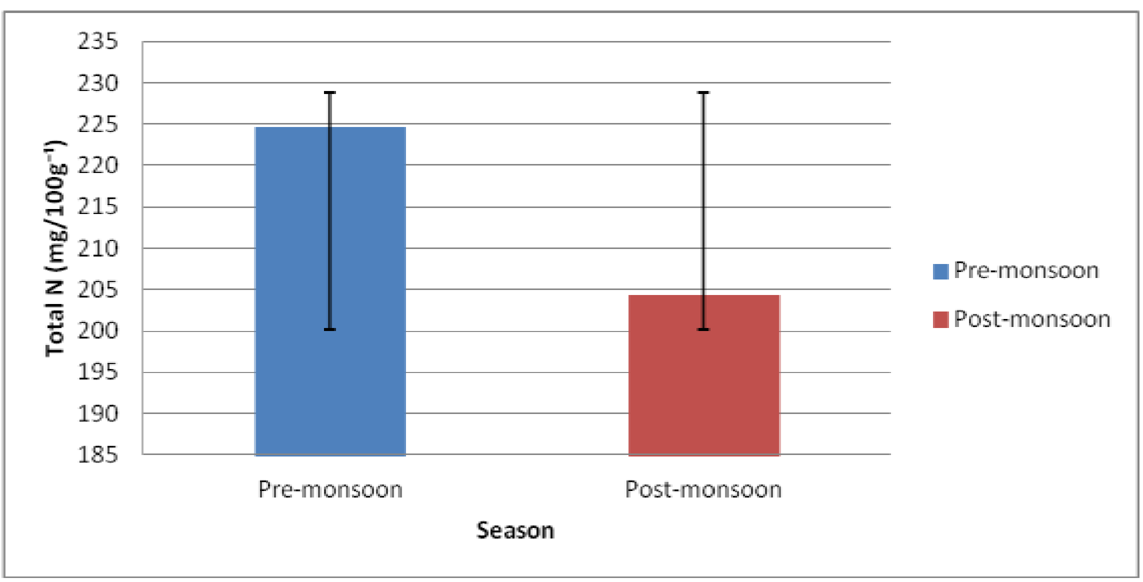

Fig. 11. Variation in Total-N during pre and post-monsoon seasons

Total Phosphorus

From table 1 and fig 12 we can observe Total Phosphorus fell from 21.45 ± 1.18 to 19.04 ± 0.79 mg 100 g^{-1} (−11.23%) in pre-and post monsoon seasons respectively. It ranges between 20.01 – 22.90 and 17.97 – 19.83 across two seasons.

It has been reported that soil phosphorous can be 500 times greater than that of overlying water. Most of the soil phosphorous is strongly absorbed on its particles and does not release in water (Masuda & Boyd, 1994). Soil phosphorous consists of organic and inorganic forms of phosphorous; however, the adsorption of different phosphorous fractions on soil sediment and their release in overlying water depend on the activity of bacteria and macrobenthos as well as abiotic parameters of soil and water at soil water interface (Shafi *et al*., 2024).

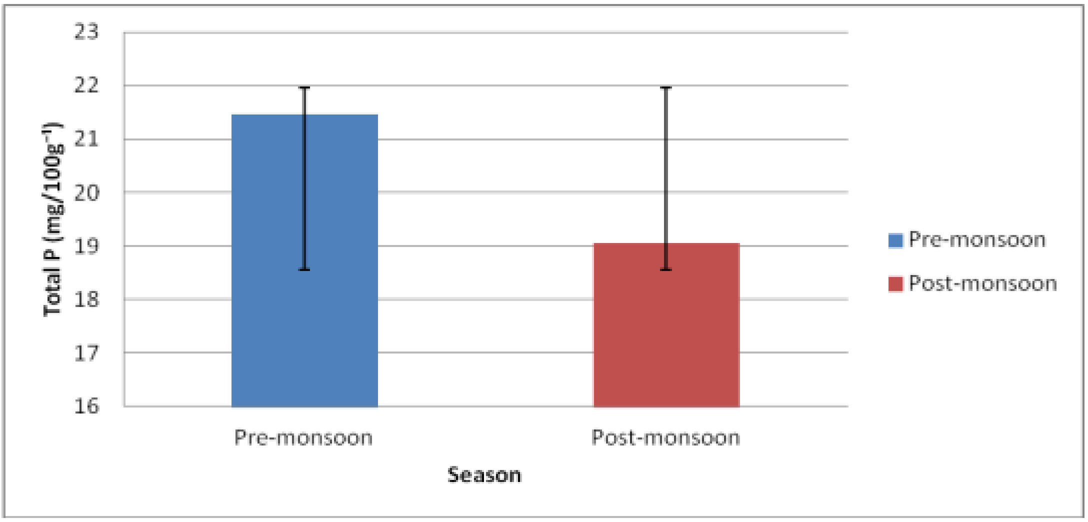

Fig. 12. Variation in Total-Pduring pre and post-monsoon seasons

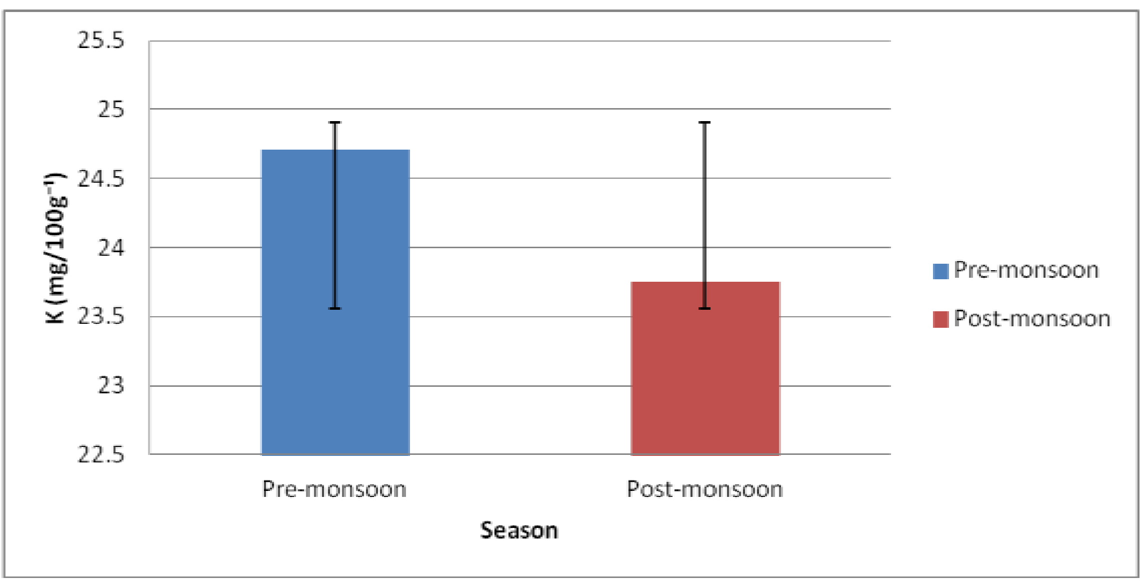

Fig. 13. Variation in Potassium during pre and post-monsoon seasons

Potassium (K)

From table 1 and fig 13 we can observe exchangeable K showed a smaller but significant decline from 24.70 ± 1.16 to 23.75 ± 1.18 mg 100 g^{-1} (−3.85%), in pre-and post monsoon seasons respectively. It ranges between 23.19 – 25.84 and 22.03 – 24.66 across two seasons. Such declines in exchangeable K subsequent monsoon period are consistent with process of leaching, runoff, and dilution of soluble K, particularly in pond sediments with moderate clay content. According to Havlin et al. (2014) and Brady & Weil (2016) potassium is known to be mobile in wet tropical soils, and significant rainfall often reduces its exchangeable portion through dislocation and transport.

CONCLUSION

Soil plays a vital role for enhancing the overall culture productivity. By implementing BMPs in four cultured grow-out ponds during two seasons the soil parameters fell in ideal range recommended by other researchers. Overall study reinforces that soil quality must be regularly monitored and managed as part of integrated pond management strategy. Effective management practices such as pond preparation, drying & tilling, liming & disinfection enhances the soil properties. However, challenges like rainfall persist, which leads in dilution of pH, EC highlighting the need for continuous monitoring.

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REFERENCES

Avnimelech, Y. (2015). *Biofloc Technology: A Practical Guidebook* (3rd ed.). World Aquaculture Society.

Balasubramanian C. P, Jayanthi M, A. Panigrahi & *et al*., (2021) Hands-on Training on Shrimp and Mud crab Culture: A Practical Exposure, Training manual series, no-18, 2nd Edition, , 176 pp.

Bansode, V. V., Sharangdhar, M. T., Mohite, A. S., Sawant, S. S., Mulye, V. B., & Chibhade, G. B. (2020). Soil and water quality parameters of brackish water shrimp farms of Raigad district of Maharashtra. *Journal of Experimental Zoology, India, 23*(Suppl. 1), 941–946. ISSN: 0972-0030.

Bhowmick, A. K., Chattopadhyay, G. N., Sah, K. D., & Sarkar, D. (2024). Assessment of Soil Factors Influencing Productivity of Fish Ponds Under Two Contrasting Agro-ecological Regions. In H. Chenchouni *et al*. (Eds.), *Recent Advancements from Aquifers to Skies in Hydrogeology, Geoecology, and Atmospheric Sciences* (pp. 111–116). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-47079-0_25

Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E., & Clark, F. E. (1965). Method of soil Analysis Par 1 and 2. Publisher Madison, Wisconsin, USA: American Society of Agronomy, Inc.

Boyd, C. E. (1995). *Bottom Soils, Sediment, and Pond Aquaculture.* Chapman & Hall. ISBN: 978-1-4615-1785-6. https://doi.org/10.1007/978-1-4615-1785-6

Boyd, C. E. (2003). Bottom Soil and Water Quality Management in Shrimp Ponds. *Journal of Applied Aquaculture, **13***(1–2), 11–33. https://doi.org/10.1300/J028v13n01_02

Boyd, C. E. (2020). *Water Quality: An Introduction.* Springer International Publishing. https://doi.org/10.1007/978-3-030-23335-8

Boyd, C. E., & Musig, Y. (1992). *Shrimp pond bottom soils: Management and treatment*. Journal of the World Aquaculture Society, 23(4), 285–293. https://doi.org/10.1111/j.1749-7345.1992.tb00024.xlibrary.enaca

Boyd, C. E., & Thunjai, T. (2002). Aquaculture pond bottom soil quality management. *Aquacultural Engineering, 27*(3), 121–145.
Boyd, C. E., & Tucker, C. S. (1998). *Pond Aquaculture Water Quality Management.* Kluwer Academic Publishers. https://doi.org/10.1007/978-1-4615-5407-3
Brady, N. C., & Weil, R. R. (2016). *The nature and properties of soils* (15th ed.). Pearson.
Carvalho, A. A., Karthikeyan, K., Sudhahar, D. J. C., & Jesiah, S. (2024). Risk Assessment and Decision-Making in Geology-Driven Projects: A Management Perspective. *Archives for Technical Sciences, 2*(31), 329–339. https://doi.org/10.70102/afts.2024.1631.329
Central Institute of Brackishwater Aquaculture (CIBA). (2019). *Soil and water quality management for shrimp farming* [Handout]. ICAR-CIBA. http://www.ciba.res.in/wp-content/uploads/2019/06/Pages-from-2019-AAHED-Handouts-Soil-water.pdfciba
Chakraborty, R., Bhowmick, S., & Mandal, R. (2017). Water and soil quality assessment in aquaculture farms: Implications for sustainability. Aquaculture Reports, 8, 1–8.
Coastal Aquaculture Authority. (2024). *Annual report 2023–2024*. Ministry of Fisheries, Animal Husbandry and Dairying, Government of India. Retrieved from https://www.caa.gov.in/annual_report.html
Corral-Pazos-de-Provens, E., Rapp-Arrarás, Í., & Domingo-Santos, J. M. (2022). Estimating Textural Fractions of the USDA Using Those of the International System: A Quantile Approach. *Geoderma, 416*, Article 115783. https://doi.org/10.1016/j.geoderma.2022.115783
Corsin, F., Mohan, C. V., Padiyar, A., Yamamoto, K., Chanratchakool, P., & Phillips, M. J. (2008). Codes of Practice and Better Management: A Solution for Shrimp Health Management? In M. G. Bondad-Reantaso *et al*. (Eds.), *Diseases in Asian Aquaculture VI* (pp. 419–432). Fish Health Section, Asian Fisheries Society.
DAHD. (2024). *Annual Report 2023–24*. Department of Animal Husbandry and Dairying, Government of India.
DoF. (2023). *Handbook on Fisheries Statistics 2022–23*. Department of Fisheries, Government of India.
Ellis, B., & Foth, H. (2018). *Soil fertility* (2nd ed.). CRC Press. https://doi.org/10.1201/9780203739341
FAO (2024). *State of World Fisheries and Aquaculture.* Food and Agriculture Organization of the United Nations, Rome.
Ghosh, A., Patra, B. C., & Chattopadhyay, D. N. (2016). Seasonal variation in nutrient dynamics of aquaculture ponds in relation to management practices. *Journal of Applied Aquaculture*, **28**(1), 61–76. https://doi.org/10.1080/10454438.2015.1094517
Government of India. (2024, March 20). *Guidelines for regulating coastal aquaculture* (CG-DL-E-21032024-253271). Ministry of Fisheries, Animal Husbandry and Dairying, Department of Fisheries. *The Gazette of India: Extraordinary, Part II, Section 3(ii).*
Haritha, J., Bhargavarami Reddy, C., Geeta Sireesha, P. V., Tirumala Reddy, S., & Naga Madhuri, K. V. (2024). Assessment of nutrient status of soils under major cropping systems of Chittoor District, Andhra Pradesh. *The Andhra Agricultural Journal*, **71**(1), 103–108. https://doi.org/10.61657/aaj.2024.99
Hasibuan, S., Syafriadiman, S., Aryani, N., Fadhli, M., & Hasibuan, M. (2023). The age and quality of pond bottom soil affect water quality and production of *Pangasius hypophthalmus* in the tropical environment. *Aquaculture and Fisheries*
Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2014). *Soil fertility and fertilizers: An introduction to nutrient management* (8th ed.). Pearson.
Hesse, P. R. (1971). *A Textbook of Soil Chemical Analysis*. John Murray.
Jackson, M.L. (1973) *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi, 498.
Kumar, P., Mishra, A., & Mohanty, R. K. (2019). Sediment characteristics and water quality dynamics in coastal aquaculture ponds of eastern India. *Aquaculture Research*, **50**(4), 1100–1112. https://doi.org/10.1111/are.13971
Lal, R. (1987). Tropical ecology and physical edaphology. Wiley

Li, L., Queiroz, J. F., & Boyd, C. E. (2015, March 1). *Pond bottom dry-out and liming, part 1*. Global Aquaculture Advocate. Global Aquaculture Alliance. Retrieved from https://www.aquaculturealliance.org/advocate/pond-bottom-dryout-liming-part-1/
Machireddy, S. R. (2025). Geospatial technology approach for soil moisture estimation in Kurnool District, Andhra Pradesh, using NDVI and LST. *Sensing and Imaging*, 26, 62. https://doi.org/10.1007/s11220-025-00598-2
Masuda, K., & Boyd, C. E. (1994). Phosphorus fractions in soil and water of aquaculture ponds built on clayey Ultisols at Auburn, Alabama. *Journal of the World Aquaculture Society*, **25**(3), 379–395. https://doi.org/10.1111/j.1749-7345.1994.tb00222.x
McCarthy, D. F. (2007). *Essentials of soil mechanics and foundations: Basic geotechnics* (6th or 7th international ed.). Pearson/Prentice Hall, Upper Saddle River, NJ.
MPEDA. (2023). *Better management practices – MPEDA.* Marine Products Export Development Authority, Kochi, India. Retrieved from https://mpeda.gov.in/?page_id=728
Muthu, N., & Sathiyamurthy, A. (2025). Evaluating soil and sediment quality in coastal regions for sustainable aquaculture development. *Natural and Engineering Sciences*, **10**(2), 393–401. https://doi.org/10.28978/nesciences.1714427
Manam, V. K. (2025). *Soil–water chemistry and its implications in aquaculture.* International Journal of Fisheries and Aquatic Studies, **13**(4), 127–132. https://doi.org/10.22271/fish.2025.v13.i5b.3152
NFDB. (2023). *National Fisheries Development Board Reports*. Ministry of Fisheries, Animal Husbandry & Dairying, Government of India.
Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *U.S. Department of Agriculture Circular* No. 939. U.S. Government Printing Office, Washington, DC. HathiTrust record: https://catalog.hathitrust.org/Record/011394670
Patel, A., & Pandit, Z. (2025). Assessment of soil and water quality in prawn aquaculture systems. *International Journal of Scientific Development and Research (IJSDR), **10***(6), 39–48. ISSN: 2455-2631.
Piper, C. S. (1966). *Soil and Plant Analysis.* Hans Publishing, Bombay, India.
Prihutomo, A., Hardanu, W., & Kartikasari, A. T. (2016). Using modified soil quality index for determining ponds bottom soil quality status of aquaculture area BLUPPB Karawang West Java, Indonesia. *Journal of Environment and Ecology*, **7**(1), 1–12. https://doi.org/10.5296/jee.v7i1.8553
Rao, G. R. M., Ranjan, R. K., & Subramanian, V. (2014). Organic matter dynamics and sediment characteristics in the Godavari estuary, India. *Environmental Earth Sciences*, **72**, 1463–1473. https://doi.org/10.1007/s12665-014-3068-3
Ratti, S. V., & Kunda, S. K. (2025a). Effects of seasonal variation and better management practices (BMPs) on water quality in *Litopenaeus vannamei* grow-out ponds. *Uttar Pradesh Journal of Zoology*, **46**(21), 44–57. https://doi.org/10.56557/upjoz/2025/v46i215328
Ratti, S. V., & Kunda, S. K. (2025b). Implications of better management practices (BMPs) on growth performance, survival rates and feed conversion ratio in Litopenaeus vannamei culture with special reference to climate change. *CIBTech Journal of Zoology*, **14**, 299–313. Centre for Info Bio Technology. http://www.cibtech.org/cjz.htm
Roy, D. R., Mondal, M., & Mondal, D. M. (2023). Physico-chemical parameters of water and soil of a few fish yielding ponds in Birbhum District of West Bengal, India.
Saraswathy, R., Ravisankar, T., Ravichandran, P., Deboral Vimala, D., Jayanthi, M., Muralidhar, M., Manohar, C., Vijay, M., & Santharupan, T. C. (2016). Assessment of soil and source water characteristics of disused shrimp ponds in selected coastal states of India and their suitability for resuming aquaculture. *Indian Journal of Fisheries*, **63**(2), 1–9. https://doi.org/10.21077/ijf.2016.63.2.45664-17

Sarma, V. V. S. S., Krishna, M. S., Rao, G. D., & Viswanadham, R. (2012). Seasonal variation of organic carbon in the coastal Bay of Bengal: Influence of river discharge and monsoon. *Journal of Geophysical Research: Oceans*, 117(C06024). https://doi.org/10.1029/2011JC007382

Shafi, J., Waheed, K. N., Mirza, Z. S., & Zafarullah, M. (2021). Variation in bottom soil quality with increasing pond age in freshwater aquaculture. *Turkish Journal of Fisheries and Aquatic Sciences*, 22(2), 97–106 https://www.trjfas.org/abstract.php?lang=en&id=14873

Shafi, J., Waheed, K. N., Mirza, Z. S., & Zafarullah, M. (2024). Stratification of soil quality indicators with increasing pond age in brackish water carps polyculture. *Journal of Applied Aquaculture*, **36**(1), 228–251. https://doi.org/10.1080/10454438.2023.2168582

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 25, 259–260.

Tenedero, R. A., & Surtida, M. B. (1986). Soil sampling and preparation for laboratory analysis. *Aquaculture Technology Module No. 5*. SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29–38. https://doi.org/10.1097/00010694-193401000-00003

Wright, A. F., & Bailey, J. S. (2001). Organic carbon, total carbon, and total nitrogen determinations in soils of variable calcium carbonate contents using a Leco CN-2000 dry combustion analyzer. *Communications in Soil Science and Plant Analysis*, 32(19–20), 3243–3258. https://doi.org/10.1081/CSS-120001118

Xinglong, J., & Boyd, C. E. (2006). Relationship between organic carbon concentration and potential pond bottom soil respiration. *Aquacultural Engineering*, **35**(2), 147–151. https://doi.org/10.1016/j.aquaeng.2005.10.002

Yuvanatemiya, V., & Boyd, C. E. (2006). Physical and chemical changes in aquaculture pond bottom soil resulting from sediment removal. *Aquacultural Engineering*, **35**(2), 199–205. https://doi.org/10.1016/j.aquaeng.2006.02.001

Yadav, G. K., Jagdhani, A. D., Sawale, D. D., Krishnapriya, M. K., & Yadav, R. S. (2019). Seasonal variation of soil chemical characteristics at Agriculture Technical School, Manjri Farm, Pune, India. *International Journal of Current Microbiology and Applied Sciences,* **8**(10), 2623–2628. https://doi.org/10.20546/ijcmas.2019.810.302