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# VARIATION IN WATER AND SOIL CHARACTERISTICS WITHIN A PRODUCTION CYCLE IN AN ALTERNATE SHRIMP-PADDY CULTIVATION PLOT IN KHULNA, COASTAL BANGLADESH

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**Abstract:** A six months study was carried out in an alternate shrimp paddy cultivation plot situated in Khulna District, Bangladesh. Na, Ca, K, Fe, P, S, $NH_4^+$-N, $NO_3^-$N, pH 8.09, Electric Conductivity (EC), redox potential (Eh) and organic carbon content in soil and water from the plot was investigated at monthly interval. P, Na, K, Fe, $NH_4^+$-N, $NO_3^-$-N, EC and Eh were increased with the progress of paddy-shrimp culture but Ca and S decreased. pH was decreased gradually in water but it was increased in soil. No significant monthly variation of the parameters, except Fe in water and Ca and $NO_3$-N in soil was observed indicating that alternate shrimp-paddy cultivation had no significant influence on the soil and water in cultivated areas.

**Key words:** Nutrient, land use management, coastal region, shrimp culture, water, soil

## Introduction

With rapidly growing aquaculture practices throughout the world, coastal aquaculture has occupied a considerable space in Bangladesh. Coastal aquaculture in Bangladesh was initiated in 1970s. Since then shrimp farming, has been an important economic activity in Bangladesh. Among the farmed shrimps, *Penaeus monodon* is one of the most important exportable commodities in Bangladesh. Coastal Bangladesh has about 120, 000 to 150,000 ha area potentially suitable for shrimp culture (Khan and Hossain, 1996).

Environmental issues associated with shrimp farming in coastal areas have been addressed by many local, national and international organizations. The rapid expansion and intensification of shrimp farming have increased concern regarding the discharge of effluent water rich in inorganic nutrients and organic matter that can lead to eutrophication of receiving water bodies (Deb, 1998; Phillips *et al*., 1993; Stanley, 1993). Several studies addressed only the water quality of shrimp farms (Islam *et al*., 2004; Wahab *et al*., 2001; Rouf, 2006). But in shrimp culture, both water and soil quality have

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been recognized as crucial factors influencing the shrimp production and the carrying capacity of the water body. Moreover, use of land for paddy and shrimp alternately is a common practice in the southeast coastal region of Bangladesh.

Considering all these, the present study was undertaken in an alternate paddy-shrimp culture plot to know the availability and trend of Na, K, P, Fe, S, NH3-N, NO3-N, pH, EC, Eh in soil and water and organic C in soil during the course of shrimp culture.

**Materials and Methods**

The study was conducted from January to June 2004 in a 1.42 ha land at *Kathaltola* village under *Dumuria* Upazila of Khulna District, Bangladesh. The land was used for shrimp and paddy cultivation alternately- paddy was cultivated during October-January and for shrimp during February-July. Table 1 describes the types of sample taken and parameters investigated during the study. The methods used in analyzing selected parameters of soil and water samples are given in Table 2.

Table 1. Types of sample taken and parameters studied during study period from the selected alternate shrimp-paddy plot in Khulna.

| Sample | Month | Sampling period | Soil | Water |
|---|---|---|---|---|
| 1 | January | Before liming (After paddy harvest) | pH, Eh, EC, Mg, Ca, Na, Fe, S, K, P, $NH_4^+N$, $NO_3^-N$ and OC | -- |
| 2 | February | After liming | Do except OC | -- |
| 3 | March | 1st MSCP | Do except OC | pH, Eh, EC, Mg, Ca, Na, Fe, S, K, P, $NH_4^+N$, $NO_3^-N$ |
| 4 | April | 2nd MSCP | Do except OC | Do |
| 5 | May | 3rd MSCP | Do except OC | Do |
| 6 | June | 4th MSCP | Do | Do |

Note: X indicates no sampling. MCP = Month of shrimp culture period.

Table 2. Method of water and soil sample analyses.

| Parameters | Method/ Procedure | Model |
|---|---|---|
| pH | Potentiometric method | Hanna bench top (pH-211) |
| Eh | Eh meter | Hanna bench top (pH-211) |
| EC | EC bridge/Conductivity meter | Hanna bench top (EC-214) |
| Potassium | Flame photometer method | Teanway (PEP-7) |
| Sodium | Flame photometer method | Teanway (PEP-7) |
| (A) $NH_4^+$-N | Kjeldahl distillation method | -- |
| (B) $NO_3^-N$ | Kjeldahl distillation method | -- |
| Phosphorus | Calorimetric method | Helios Epsilon (9423UVE 1000 E) |
| Organic carbon | Titrimetric method (Wakly & Blaeks wet oxidation) | -- |
| Calcium | Complexometric titration method (EDTA) | -- |
| Iron (Fe) | Calorimetric method | Helios Epsilon (9423UVE 1000 E) |
| Sulfur (S) | Turbimetric method | Helios Epsilon (9423UVE 1000 E) |

Each soil sample was a homogenous mixture of soils collected from 8 to 10 different places of the selected plot. Water samples were collected from surface layer of the water body. Water and soil samples were collected in plastic jars and poly bags respectively. All the samples were preserved at the Laboratory of Fisheries and Marine Resource Technology, Khulna University prior to analyses. Various standard methods were used in measuring selected water and soil parameters (Table 2). Data were presented in tables and analyses (one-way ANOVA) performed with SPSS-12 software.

## Results

For the selected parameters monthly mean, total mean, standard deviation and P value are presented in Table 3 for water and Table 4 for soil.

The nutrient contents of soil showed a considerable variation between the dried and wet period whereas nutrient contents of water was changed with the length of culture period and with the exchange of saline water in the *gher*. It was observed that concentration of P, Na, K, Fe, $NH_4^+$-N and $NO_3^-$N increased with the culture period and at the end of the shrimp culture on the other hand some nutrients i.e. Ca and S were decreased. The most important water quality parameter, pH, was decreased gradually from the water but it was increased in soil. Other water quality parameters like EC and Eh were increased with shrimp culture in both soil and water. Organic carbon recorded in the soil, was increased (3.36 %) at the end of shrimp culture. Statistical analysis of P value (Table 3 and Table 4) suggested that there was no significant monthly variation except water Fe in water and Ca and $NO_3^-$N in soil.

Significant positive correlation was found between pH – P, EC-Eh, EC- Ca, $NH_4^+$-N – K, EC - $NO_3^-$-N, $NO_3^-$-N - Ca for soil and Eh - $NH_4^+$-N, Eh – P, Eh – Fe, $NH_4^+$-N – P, $NH_4^+$-N – Fe, P – Fe for water. But significant negative correlation was found between pH-Eh, pH - $NH_4^+$-N, pH – P, and pH-Fe for water (Table 5 and 6).

## Discussion

***pH*:** Water pH observed in this study is well inside the optimum range for shrimp culture (7.5–8.9, Anon, 1995). However, the trend of reduction in water pH at the end of the culture period could be associated with rainfall (Dao *et al*., 2002) and also with the input of water containing fertilizers and effluents from the adjacent rice culture farms. The soil pH ranged between 7.73 and 8.61 indicates average potential for aquaculture production (Boyd, 2003). A little increment of soil pH due to shrimp culture indicates poor influence of the present land use. Liming before entering water in *gher* might be responsible for increasing soil pH (Table 5) , which is in agreement with the findings of the increase in soil pH in one or two months after liming (Queiroz *et al.,* 2004).

***Electric conductivity (EC):*** EC for soil were found to be inconsistent. It is assumed that liming might had increased EC of soil. The soil EC may also vary with water depth and seasons. According to FAO (Anon, 1985), EC values for the soil samples from Satkhira, Bangladesh (Brackish water) range between 600 and 1300 ms $m^{-1}$. Smith (1996) reported that soil conductivity of prawn ponds ranged between 700 and 100 ms $m^{-1}$. The desired range of water EC for fishpond is recommended as 10-200 ms $m^{-1}$ (Stone and Thomforde, 2001). Entrance of saline water, and evaporation might be responsible for the fluctuations of EC values in water.

***Redox-potential (Eh):*** The water Eh values were found to be less consistent with a sharp rise during the harvest period. Suspended materials could be responsible for this higher redox potential. Chaimberlain (1989) reported the redox potential in a shrimp pond as +45 mv at mid-water column, 0 to -15 mv just above the mud and -316 mv at 2 cm within

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Table 3. Water parameters of the experimental gher during the study period.

| Months | pH | EC (ms $m^{-1}$) | Eh (mv) | $NH_4^+$ N (mg $l^{-1}$) | $NO_3^-$ N (mg $l^{-1}$) | P (mg $l^{-1}$) | K (mg $l^{-1}$) | S (mg $l^{-1}$) | Fe (mg $l^{-1}$) | Na (mg $l^{-1}$) | Ca (mg $l^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mar | 8.43 | 30.3 | -80.1 | 22.93 | 6.59 | 0.012 | 115 | 275 | 0.06 | 900 | 375 |
| Apr | 8.61 | 32.8 | -91.2 | 16.38 | 9.83 | 0.027 | 155 | 325 | 0.03 | 1095 | 425 |
| May | 8.39 | 42.6 | -79 | 19.66 | 49.13 | 0.011 | 155 | 285 | 0.13 | 1155 | 450 |
| Jun | 7.73 | 35.5 | -42 | 113.23 | 5 | 3.24 | 117 | 250 | 2.77 | 1055 | 350 |
| Mean | 8.29 | 35.3 | -73.08 | 43.05 | 17.64 | 0.82 | 135.5 | 283.75 | 0.75 | 1051.25 | 400 |
| SD | 0.39 | 5.31 | 21.44 | 46.86 | 21.09 | 1.61 | 22.53 | 31.19 | 1.35 | 108.89 | 45.64 |
| Range | 7.73-8.61 | 30.3-42.6 | (-42)-(-91.2) | 16.38-113.23 | 5-49.13 | 0.011-3.24 | 115-155 | 250-325 | 0.03-2.77 | 900-1155 | 350-450 |
| Standard | 6.5–8.5 | - | - | TN*: 0.4 | | 0.02 | 380 | 900 | 0.1 | 10,500 | 400 |
| P value | 0.02 | 0.035 | 0.027 | 0.06 | 0.06 | 0.03 | 0.017 | 0.03 | 0.03 | 0.04 | 0.03 |

TN*: Total Nitrogen

Table 4. Soil parameters of the experimental gher during the study period.

| Months | pH | EC (ms $m^{-1}$) | Eh (mv) | $NH_4^+$ N (mg $l^{-1}$) | $NO_3^-$ N (mg $l^{-1}$) | P (mg $l^{-1}$) | K (mg $l^{-1}$) | S (mg $l^{-1}$) | Fe (mg $l^{-1}$) | Na (mg $l^{-1}$) | Ca (mg $l^{-1}$) | OC (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan* | 8.07 | 2.18 | -71.08 | 203.28 | 34 | 7.44 | 400 | 82.5 | 0.79 | 5 | 350 | 1.76 |
| Feb** | 8 | 7.3 | -56 | 65.52 | 327.6 | 4.32 | 360 | 75 | 1.19 | 18 | 455 | |
| Mar*** | 8.08 | 3.5 | -62.1 | 327.6 | 65.52 | 4.26 | 500 | 30 | 0.89 | 8 | 350 | |
| Apr*** | 8.07 | 4.2 | -61 | 196.57 | 65.51 | 4.56 | 500 | 11.25 | 1.19 | 10 | 350 | |
| May*** | 8.1 | 5.3 | -63.7 | 393.12 | 131.04 | 6.96 | 600 | 50 | 0.79 | 21 | 355 | |
| Jun*** | 8.21 | 4.2 | -68 | 300 | 65 | 9.84 | 475 | 31.25 | 1.19 | 18 | 355 | 3.36 |
| Mean | 8.09 | 4.45 | -63.65 | 247.68 | 114.78 | 6.23 | 472.5 | 46.67 | 1.01 | 13.33 | 42.12 | 2.56 |
| SD | 0.07 | 1.73 | 5.33 | 116.66 | 109.01 | 2.25 | 84.48 | 27.81 | 0.2 | 6.5 | 369.17 | |
| Range | 8-8.21 | 2.18-7.3 | (-71.18) -(-61) | 65.52 -393.12 | 34-131.04 | 4.26-9.84 | 360-600 | 11.25 -82.50 | 0.79-1.19 | 5-21 | 350-455 | |
| P value | 0.02 | 0.04 | 0.05 | 0.06 | 0.06 | 0.04 | 0.05 | 0.04 | 0.03 | 0.04 | 0.03 | |

**Note:** * = month represents before liming; ** = month represents after liming and *** =month represents shrimp culture period. Standard: Boyd (1989)

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Table 5. Correlation between the soil parameters.

| Parameter | | pH | EC | Eh | $NH_4^+N$ | $NO_3^-N$ | P | K | S | Fe | Na | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | Pearson Correlation | 1 | -.367 | -.619 | .631 | -.586 | .831* | .426 | -.442 | .074 | .226 | -.596 |
| | Sig. (2-tailed) | | .474 | .190 | .179 | .222 | .040 | .400 | .381 | .889 | .667 | .211 |
| EC | Pearson Correlation | -.367 | 1 | .813* | -.367 | .926** | -.317 | -.111 | .128 | .480 | .771 | .829* |
| | Sig. (2-tailed) | .474 | . | .049 | .474 | .008 | .541 | .834 | .809 | .335 | .072 | .041 |
| Eh | Pearson Correlation | -.619 | .813(*) | 1 | -.421 | .770 | -.780 | -.099 | -.138 | .465 | .345 | .696 |
| | Sig. (2-tailed) | .190 | .049 | . | .405 | .073 | .067 | .851 | .794 | .353 | .503 | .125 |
| $NH_4^+N$ | Pearson Correlation | .631 | -.367 | -.421 | 1 | -.579 | .394 | .876* | -.407 | -.541 | .164 | -.738 |
| | Sig. (2-tailed) | .179 | .474 | .405 | . | .228 | .440 | .022 | .424 | .268 | .756 | .094 |
| $NO_3^-N$ | Pearson Correlation | -.586 | .926** | .770 | -.579 | 1 | -.402 | -.409 | .430 | .365 | .560 | .966** |
| | Sig. (2-tailed) | .222 | .008 | .073 | .228 | . | .430 | .420 | .394 | .477 | .247 | .002 |
| P | Pearson Correlation | .831* | -.317 | -.780 | .394 | -.402 | 1 | .136 | .089 | -.081 | .267 | -.377 |
| | Sig. (2-tailed) | .040 | .541 | .067 | .440 | .430 | . | .798 | .866 | .880 | .609 | .461 |
| K | Pearson Correlation | .426 | -.111 | -.099 | .876* | -.409 | .136 | 1 | -.581 | -.351 | .302 | -.627 |
| | Sig. (2-tailed) | .400 | .834 | .851 | .022 | .420 | .798 | . | .226 | .495 | .560 | .182 |
| S | Pearson Correlation | -.442 | .128 | -.138 | -.407 | .430 | .089 | -.581 | 1 | -.376 | -.006 | .498 |
| | Sig. (2-tailed) | .381 | .809 | .794 | .424 | .394 | .866 | .226 | . | .463 | .990 | .315 |
| Fe | Pearson Correlation | .074 | .480 | .465 | -.541 | .365 | -.081 | -.351 | -.376 | 1 | .281 | .444 |
| | Sig. (2-tailed) | .889 | .335 | .353 | .268 | .477 | .880 | .495 | .463 | . | .589 | .378 |
| Na | Pearson Correlation | .226 | .771 | .345 | .164 | .560 | .267 | .302 | -.006 | .281 | 1 | .403 |
| | Sig. (2-tailed) | .667 | .072 | .503 | .756 | .247 | .609 | .560 | .990 | .589 | . | .428 |
| Ca | Pearson Correlation | -.596 | .829* | .696 | -.738 | .966** | -.377 | -.627 | .498 | .444 | .403 | 1 |
| | Sig. (2-tailed) | .211 | .041 | .125 | .094 | .002 | .461 | .182 | .315 | .378 | .428 | . |

Number of observation = 18; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

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Table 6. Correlation between the water parameters.

| Parameters | | pH | EC | Eh | $NH_4^+N$ | $NO_3^-N$ | P | K | S | Fe | Na | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | Pearson Correlation | 1 | -.144 | -1 ** | -.978* | .253 | -.968* | .602 | .860 | -.975* | .009 | .711 |
| | Sig. (2-tailed) | . | .856 | .000 | .022 | .747 | .032 | .398 | .140 | .025 | .991 | .289 |
| EC | Pearson Correlation | -.144 | 1 | .127 | .014 | .899 | .023 | .536 | -.115 | .052 | .810 | .574 |
| | Sig. (2-tailed) | .856 | . | .873 | .986 | .101 | .977 | .464 | .885 | .948 | .190 | .426 |
| Eh | Pearson Correlation | -1 ** | .127 | 1 | .977* | -.266 | .965* | -.621 | -.869 | .972* | -.033 | -.725 |
| | Sig. (2-tailed) | .000 | .873 | . | .023 | .734 | .035 | .379 | .131 | .028 | .967 | .275 |
| $NH_4^+N$ | Pearson Correlation | -.978* | .014 | .977(*) | 1 | -.402 | .998** | -.588 | -.758 | .998** | -.019 | -.755 |
| | Sig. (2-tailed) | .022 | .986 | .023 | . | .598 | .002 | .412 | .242 | .002 | .981 | .245 |
| $NO_3^-N$ | Pearson Correlation | .253 | .899 | -.266 | -.402 | 1 | -.401 | .647 | .122 | -.373 | .660 | .792 |
| | Sig. (2-tailed) | .747 | .101 | .734 | .598 | . | .599 | .353 | .878 | .627 | .340 | .208 |
| P | Pearson Correlation | -.968* | .023 | .965* | .998** | -.401 | 1 | -.546 | -.718 | .999** | .024 | -.730 |
| | Sig. (2-tailed) | .032 | .977 | .035 | .002 | .599 | . | .454 | .282 | .001 | .976 | .270 |
| K | Pearson Correlation | .602 | .536 | -.621 | -.588 | .647 | -.546 | 1 | .774 | -.541 | .803 | .940 |
| | Sig. (2-tailed) | .398 | .464 | .379 | .412 | .353 | .454 | . | .226 | .459 | .197 | .060 |
| S | Pearson Correlation | .860 | -.115 | -.869 | -.758 | .122 | -.718 | .774 | 1 | -.734 | .307 | .702 |
| | Sig. (2-tailed) | .140 | .885 | .131 | .242 | .878 | .282 | .226 | . | .266 | .693 | .298 |
| Fe | Pearson Correlation | -.975* | .052 | .972* | .998** | -.373 | .999** | -.541 | -.734 | 1 | .037 | -.719 |
| | Sig. (2-tailed) | .025 | .948 | .028 | .002 | .627 | .001 | .459 | .266 | . | .963 | .281 |
| Na | Pearson Correlation | .009 | .810 | -.033 | -.019 | .660 | .024 | .803 | .307 | .037 | 1 | .662 |
| | Sig. (2-tailed) | .991 | .190 | .967 | .981 | .340 | .976 | .197 | .693 | .963 | . | .338 |
| Ca | Pearson Correlation | .711 | .574 | -.725 | -.755 | .792 | -.730 | .940 | .702 | -.719 | .662 | 1 |
| | Sig. (2-tailed) | .289 | .426 | .275 | .245 | .208 | .270 | .060 | .298 | .281 | .338 | . |

Number of observation = 16; ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

the black mud. In the present study, the average soil Eh was substantially higher.

***Iron (Fe):*** Boyd (1989) reported a standard Iron concentration for shrimp farm water at 0.01 mg $l^{-1}$. Concentration of dissolved iron in the present study was more or less similar, within the standard for first three months and with high concentration at the end of the culture period. There is no clear evidence that soluble iron concentrations up to 1.0 mg $l^{-1}$ or even higher in aerobic water harms fish and shrimp (Boyd and Tucker, 1998). Present data showed that Iron is inversely correlated with the pH (Table 6), which is also supported by Tho *et al.* (2006). Water pH was reduced from the month of May up to the end and thus iron content in water was sharply raised from that month to the end in shrimp ponds. However, as iron easily binds to chelators, actual concentrations are always higher than the expected concentrations (Huntsman and Sunda, 1980). Speciation of dissolved iron is related with water Eh. Generally lower Eh facilitates the formation of $Fe^{2+}$. Therefore $Fe^{2+}$ compound shows higher solubility than their $Fe^{3+}$ compounds at lower Eh. This might be the reason to get positive relation between Eh and Fe (Table 6). Although Soil Fe values showed a zig-zag trend, the values were found to be lower as compared to the values of 44 mg $l^{-1}$ in soil cores from pond of pH 7.17 at Muňoz, the Philippines (Boyd *et al.,* 2002).

***Sodium (Na):*** Sodium content in water was increased with the gradual increase in water salinity from March to May. Soil sodium content exhibited the same pattern. Sodium content of soil affects the soil texture and pH. Boyd *et al.* (2002) reported pH 8 or above in soil with high concentrations of sodium.

***Calcium (Ca):*** The concentration of dissolved calcium was more or less similar to the standard for shrimp culture pond of 400 mg $l^{-1}$ (Boyd, 1989). Water exchange rate may be responsible for Ca content in the farm water. Calcium content could vary with the molting rate of shrimp. Shrimp absorbs calcium from the water. The reduction of calcium in water was mainly due to the uptake of calcium by shrimp to meet physiological requirements (Fiber and Lutz, 1982).

The observed Ca values in soil were much lower than that suggested (4435 mg $l^{-1}$) by Boyd *et al.* (2002). However, a sharp rise in calcium content was observed in February, and might be associated with evaporation, lime application, and degradation of paddy field waste.

***Potassium (K):*** Observed K content in water was lower than the standard for shrimp culture (380 mg $l^{-1}$; Boyd, 1989). It is noticeable that soil K increased with the shrimp culture activities and dropped at the harvesting month (June). Boyd *et al.* (2002) reported that the soil cores having pH 7.17 in a tilapia fish pond contains K 88 mg $l^{-1}$, but the observed values were considerably higher. Entrance of saline water in the fish pond studied might have influenced K content in both water and soil.

***Phosphorus (P):*** Observed dissolved P was in the agreement with the findings (0.0112 and 0.384 mg $l^{-1}$) of Wahab *et al.* (2001) in different shrimp farms. Variation of total phosphate content depends on water salinity, supply source and management practice. NACA (Anon, 1995) reported that the phosphate content of shrimp pond water increases with increasing stocking density. According to Dao *et al.* (2002), the highest content could be found in the month with heavy rain. Heavy shower in the monsoon is responsible for the increased amount of phosphate phosphorus content (Lee and Wickins, 1992). In the present study, the highest concentration of P in water was found in June, which is the starting month of monsoon in Bangladesh. Moreover, P fixation increases with increasing $Ca^+$ in water within the alkaline water pH. That is why P availability increases with reducing water pH (Table 6). But positive relation found between P and Fe (Table 6) as P and Fe react with each other to form insoluble iron phosphorus with the declining (beyond 6) water pH.

The phosphorus level in soil was more or less within the range of 2.7 -7.5 mg $g^{-1}$ (Wahab and Stirling, 1991). In the present study, the soil phosphorus decreased in dry month (February), which might be associated with the acid sulfate soil (Kyuma, 2003). However, it is well documented that the availability of phosphorus in fishpond is largely associated with feed used, fertilizers applied, detritus and adjacent environments. Present data showed positive relation between soil P and pH (Table 5) as it is known that the highest P availability is found within 6-7 pH due to lowest degree of fixation.

***Sulfur (S):*** In aquaculture, typical level of sulfate ranges from 0 to 1000 mg $l^{-1}$ (Boyd, 1989). Fish tolerate a wide range of sulfate concentrations. Sulfur content of water in the present study was lower than the standard of 900 mg $l^{-1}$ for sea-water (Boyd, 1989). Sulfur content in soil was considerably higher due to water sources and environment in coastal vicinity. Smith (1996) reported an underestimated sulfur value of 2.9 mg $l^{-1}$ from the centre of coastal prawn ponds, due to loss of sulfur as $H_2S$ during sample preparation. After re-watering the pond a substantial reduction in sulfur –content in soil was observed.

***Nitrate-nitrogen ($NO_3^-$-N):*** NACA (Anon, 1995) reported that shrimp can grow normally even at concentrations of 300 mg $l^{-1}$ of nitrate. Thus observed nitrate content was acceptable for shrimp farming. However, increased nitrate content in water observed in the present study could be due to seepage of fertilizer rich water from adjacent water bodies. Deb (1998) reported nitrate at 0.05-1.54 mg $l^{-1}$ in the waste water of intensive shrimp pond. For soil, the highest $NO_3^-$-N value in February could be attributed to the decomposition of rice field materials, and it dropped to 65.52 mg $l^{-1}$ by the next month due to the application of lime. Nitrate nitrogen may affect soil EC by affecting the solubility of its associated cation. Thus there is a positive correlation between nitrate nitrogen and EC. The positive relation between nitrate nitrogen and Ca may also be explained in the similar way (Table 5).

***Ammonium-nitrogen ($NH_4^+$-N):*** Total ammonia concentration generally increases as feeding rate increases in response to fish growth and fish stocking (Tucker *et al.,* 1979), and as feed protein level is increased at equal feeding rates. The present study shows that the highest concentration of ammonium-nitrogen was observed in summer, growing season, which is in accordance with Tucker *et al.* (1979). But in spring (April), the values in water were found to be reduced which could be due to rapid nitrification. As pH increases, proportion of unionized ammonia ($NH_3$) increases (Stone and Thomforde, 2001). Since ammonia gas reacts with free proton to form ammonium ion therefore formation of ammonium requires acidic pH. Thus $NH_4^+$-N showed inverse relation with water pH in the present study (Table 6). Reduction stage of water increases the probability of accumulating ammonium. Present data showed positive correlation between Eh and $NH_4^+$-N (Table 6). This might be due to the activation of ammonia utilizing micro-organisms in water at lower Eh. The trend of $NH_4^+$-N values in soil samples seemed not to be well explicable in the present study. The percentage of free ammonia considering pH range of 4-12 mg $l^{-1}$ (Farmer, 1989). According to Wahab *et al.* (2001), ionized ammonia or $NH_4^+$ is considered non-toxic to fish and crustacean animals. But total ammonia nitrogen (TAN=$NH_4^+$-N+$NH_3$-N) is critical for aquaculture, and Jifsan (2007) recommended 1.67 or less mg $l^{-1}$ total ammonia nitrogen suitable for shrimp farms. Wahab *et al.* (2001) reported the minimum and the maximum values of TAN at 1.08 mg $l^{-1}$ and 2.43 mg $l^{-1}$ in shrimp farms, respectively.

***Organic carbon:*** According to Boyd (2003), the pond soil containing 1.5 to 2.5 % organic carbon is of high potential for aquaculture and containing >2.5% is of low potential. Boyd *et al.* (2002) reported 2.84% total carbon in soil cores of pH 7.17. Unused feed, faecal matter, dissolved solids, carbonaceous matter and dead plankton, etc. settling down at the pond bottom results in the accumulation of organic loads. The increased content of organic carbon at the end of the present experiment indicates the accumulation of organic mater on the pond bottom, which is in agreement with the findings of Shanthi *et al.* (2004).

## Conclusion

The nutrient loads increased with the progress in shrimp culture except inconsistent sulfur and calcium for both soils and water. However, liming seems to have major influence in changing the water and soil parameters. It was revealed that most of the water parameters were associated with pH and Eh whereas soil parameters are associated with pH and EC. The trend of different parameters for water and soil found in the present work could be used to develop a primary model for a sustainable shrimp-paddy cultivation system.

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