

Identification of soil properties influencing primary productivity of fish ponds under red and lateritic soil zones

A. Banerjee¹ and G.N. Chattopadhyay^{2*} 

¹Department of Botany, Polba Mahavidyalaya, Polba-712 148, India

²School of Agriculture, Seacom Skills University, Kendradangal-731 236, India

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*Corresponding Author Email : gunin.c2010@gmail.com

*ORCID: <https://orcid.org/0000-0002-5474-9565>

Abstract

Aim: The present study aimed to identify the key soil factors influencing the primary productivity of water in the fish ponds situated under low productive red and lateritic soil zones.

Methodology: General properties of fish pond soils (n=42) from different red and lateritic soil zones of West Bengal, India were determined along with the gross primary productivity (GPP) values of corresponding pond waters. All the soil properties were correlated with GPP values and the soil factors which were significantly correlated with GPP of pond water were further used for step down regression analysis with regard to GPP. This helped to develop a minimum data set of the key soil factors which showed maximum influence on GPP. The efficiency of the regression equation, generated with the critical soil parameters, in predicting the GPP values of other ponds was also assessed through a study on the variations in calculated and on-farm GPP values of eight fish ponds.

Results: Among all the studied soil properties, pH and availability of three major nutrients viz. N, P and K were observed to contribute 84.15% variations in gross production of primary fish food organisms in these pond environment. Of these 4 soil properties, again, pH and available P values of the pond soils appeared to be more important. A regression equation was also developed to predict the GPP of such pond water using soil pH and available P values only. This equation showed a precision range of 83.0 to 99.7% and was found to be statistically at par with the GPP values observed under actual pond condition.

Interpretation: High efficiency in predictability of pond GPP values using the minimum data set of two key soil factors viz. soil pH and available P indicates that proper management of these productivity attributing soil properties will be particularly helpful to improve the primary productivity levels of the predominantly low yielding fish ponds under the red and lateritic soil zones.

Key words: Fish ponds, Minimum data set, Productivity attributes, Red and lateritic soil zones, Soil factors



Introduction

Role of bottom soils in influencing the environment and productivity of various pond fish culture systems are well documented. Not only this phase helps in gradual release of different nutrients to available forms for the benefit of primary fish food organisms and, in turn, the growth of fishes but it also helps to maintain a favorable pond environment through various biochemical reactions occurring in these aquatic ecosystems (Adhikari, 2011; Boyd, 2012; Vass *et al.*, 2015). Considering the importance of bottom soils on productivity of fish ponds, Hickling (1971) designated this phase as the “Chemical laboratory of a fish pond”. Basic properties of a soil group being largely different from the other ones, the fish ponds situated under a particular soil zone are likely to exhibit some specific characters of soil and water environment, which may be reflected in their biological productivity levels also. Considering this fact, Boyd *et al.* (2002), while discussing different aspects of aquaculture pond bottom soil management, suggested that the location specific soil deficiencies should be identified and treated while undertaking new fish culture programmes in any fish pond. Similar importance of soil system based pond management by taking into account the major productivity attributing soil factors for any particular soil condition has been discussed by Banerjee *et al.* (2010) and Chattopadhyay (2018).

Red and lateritic soils form an important soil group of the tropical and sub-tropical countries covering approximately 13% of the total land areas of the world. Such soils occur extensively in the South Asia, Western and Central Africa, many parts of South America, South-East Asia, Australia, India, China, Japan etc. (Sehgal, 1998). In India, the red and lateritic soils cover a total area of about 110 million ha, out of which 70 Mha is occupied by red soil. The red and lateritic soils in India have developed under varying physiographic and climatic conditions in the tropical and subtropical climates with rainfall ranging between 600 to 4000 mm and mean annual temperature between 22 and 30°C with narrow differences between mean summer and mean winter soil temperatures (Ghosh, 2019). The productivity levels of these soils are usually of low order owing to various soil related constraints like acidic pH, restricted availability of nutrients like nitrogen, phosphorus and potassium, light texture, low cation exchange capacity, poor water retentivity, low organic carbon content etc. (Sarkar, 2013). Fish yield of the ponds located in these soil zones are generally lower as compared to the ponds situated in nearby alluvial soil zones (Bhowmick *et al.*, 2022). This has been attributed to the low range of primary food production in these ponds owing to the influence of some adverse soil properties on pond environment (Chattopadhyay and Banerjee, 2005).

In this study, an attempt was made to identify the major soil factors associated with primary fish food production in the ponds located under red and lateritic soil zone. It has been hypothesized that screening of a minimum data set of the identified key productivity determining soil factors and their management will help in improving the primary productivity and,

thereby, the yield levels of these low productive fish ponds of the red and lateritic soil regions which occur extensively in tropical and sub-tropical regions.

Materials and Methods

Forty two bottom soil samples were collected from fish ponds situated in various red and lateritic soil zones of Bankura, Birbhum, Puruliya and West Burdwan districts covering the major stretch of red and lateritic soils in West Bengal, India at 86000'00"– 89000'00" E longitude and 21030'00"— 24030'00" N in latitude (Fig. 1). Fish ponds were selected randomly, taking the help of local administration. Surface soils, up to a depth of 15cm, were collected manually while primary productivity studies were carried out in the surface water layer covering a depth of 30 cm. The collected soil samples were air dried, ground and sieved to 80 mesh size for the analyses of pH (1:2), organic carbon (Walkley and Black, 1934), available nitrogen (Subbiah and Asija, 1954), available phosphorus (Bray's extractant no.1), available potassium (Jackson, 1973), texture and available micro nutrients (Fe, Mn, Cu and Zn) following standard protocols. The pH was determined with the help of an electrically operated pH meter, nitrogen was estimated by Kjeldtech apparatus, phosphorus was determined with a spectrophotometer and potassium was estimated using a flame photometer. Analyses of the micronutrients were carried out with the help of an atomic absorption spectrophotometer using DTPA extraction of these micronutrients as described by Lindsay and Norvell (1978).

Since most of these soil properties are likely to be influenced by submerged condition of the pond soils, the processed soil samples required for estimating parameters, other than texture and organic carbon, were incubated under submerged condition for 10 days using 1:10 soil water ratio for developing a semi-aerobic condition in the soil simulating to fish pond condition and then used for the estimations. Water samples of all the fish ponds were analyzed for gross primary productivity (GPP) values by incubating the fresh water samples in light and dark bottles and estimating the dissolved oxygen by following the principle described by Odum (1973). Statistical analyses of the results were carried out at three phases using SPSS software (v.21). During the first phase, correlation coefficients of different soil properties with the dependent variable GPP were estimated. The soil factors which came out to be significantly correlated with GPP of water were further selected for step down regression analysis with regard to GPP. This helped to develop several prediction equations to calculate the probable GPP values of water using the key soil factors. From these, the most convenient equation with minimum data set (MDS) was selected for predicting the on-farm GPP values. During the third phase, the path co-efficient analysis was adopted for assessing the results further. The precision of the most convenient equation in predicting the GPP of the fish pond water using only pH and available phosphorus values of bottom soils was also assessed through a study on eight fish ponds from the red and lateritic soil zones. Since the results of this assessment study could be

influenced due to inclusion of the previously sampled ponds, fresh fish ponds, other than those studied earlier, were selected for this purpose. The GPP values of water as well as pH and available phosphorus levels of these pond soils were estimated and the obtained values were put to the prediction equation (no. 3) for calculating the GPP of water. The precision level of the prediction equation was calculated separately for each pond by

the following formula:

$$\text{Precision \%} = \frac{\text{Calculated GPP}}{\text{On-farm GPP}} \times 100$$

The significance of difference between the actual GPP values under on-farm condition and the corresponding predicted GPP values were estimated statistically through paired t-test.

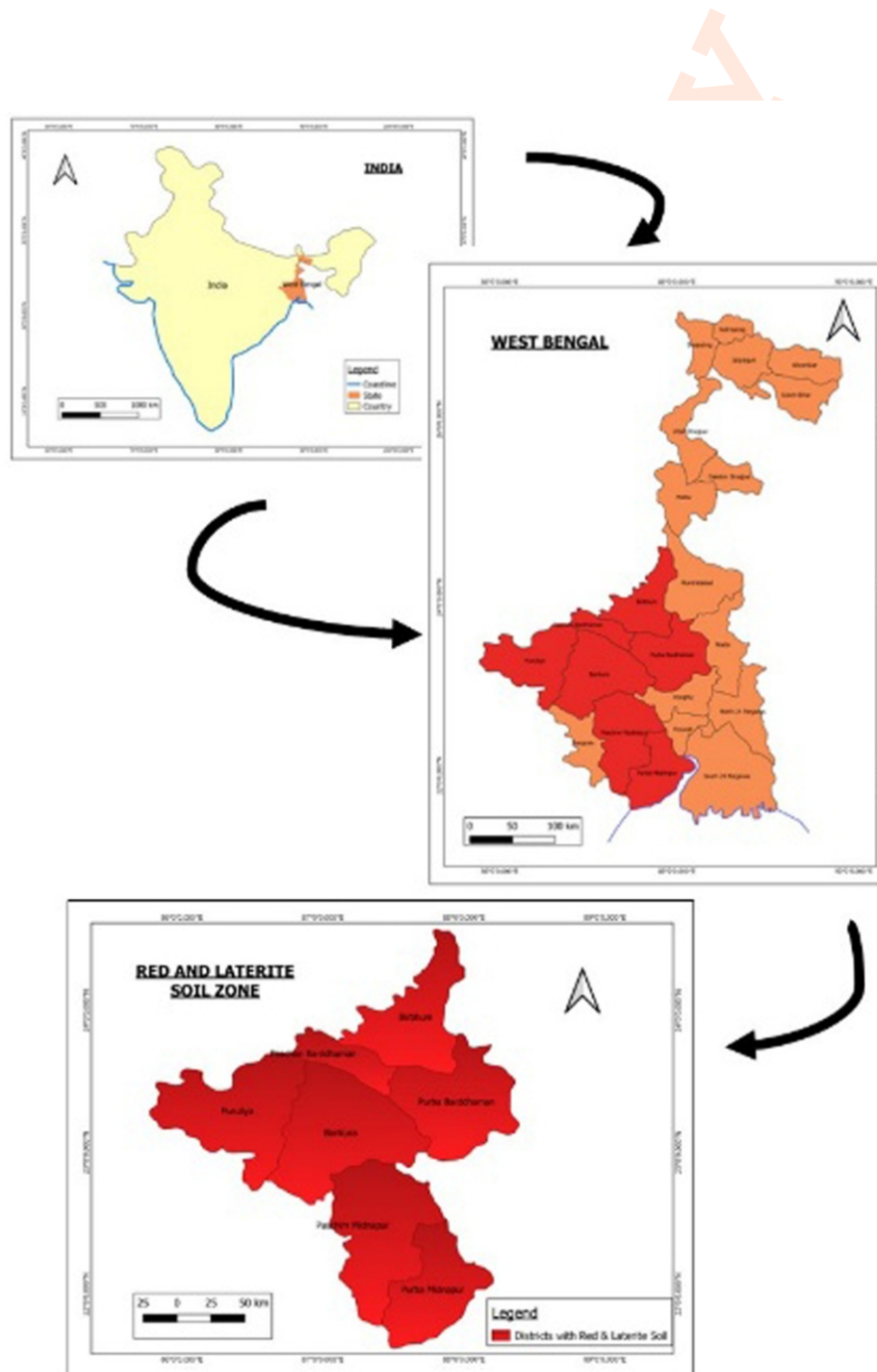


Fig. 1: Location of the area under study.

Results and Discussion

Ranges of different soil properties of fish ponds located under the red and lateritic soil zones and their average values are presented in Table 1. The pH values of pond soils appeared to be predominantly acidic, ranging between 3.3-7.0 with a median value of 5.15. Of the studied pond soils, 92.9 % exhibited pH values below 6.5, and 47.6 % were even below 5.5. Such wide occurrence of acidic pH values in fish ponds of red and lateritic soils is well documented (Bhowmick *et al.*, 2022) and attributes to moderate to highly weathered nature of these soils and also enrichment with Fe and Al rich minerals (Sarkar, 2013). More favorable influence of neutral to slightly alkaline pH for bottom soils, over the acidic ones, in sustaining productivity of fish ponds has been emphasized by many researchers (Boyd, 2012; Adhikari, 2011). Such influence of pH on pond productivity is primarily attributed to more conducive nutritional status as well as physiological functions under neutral to slightly alkaline soil water conditions as compared to those under acidic environments (Chattopadhyay, 2018). The predominance of acidic bottom soils in the fish ponds under red and lateritic soil zones may, therefore, be considered to be a major constraint for maintaining their productivity.

Organic carbon content of these pond soils varied

between 0.07 and 1.5 % with an average value of 0.78%. While discussing the nature and properties of fish pond soils, Boyd *et al.* (2002) suggested occurrence of less than 1.0 % of organic carbon to be indicative of low productivity in pond soils. Considering his views, 92.7 % of the studied pond soils of red and lateritic soil zones may be considered to be poor in organic carbon. Production of fish food organisms contribute largely to accumulation of organic matter in bottom soils of fish ponds (Boyd, 2012). In the present case, the primary productivity levels of the studied fish ponds appeared to be rather low (Table 1), as per the suggested value of 13.7 g C per m³ day⁻¹ for production of 1000 kg fish ha⁻¹ (Mandal and Chattopadhyay, 1992). Such low rate of primary production probably restricted the formation of organic materials in the pond bottoms. In addition, a large number of fish ponds in red and lateritic soil zones tend to dry up during the exhaustive summer of tropical climate. This promotes the oxidation of organic materials in bottom soils lowering the organic carbon content of these soils further. The low occurrence of organic carbon may affect other soil properties like availability of different nutrients, cation-exchange capacity, water retention etc., the properties that are closely related with organic carbon content of the pond soils. Available nitrogen values of the soils ranged between 21.5 to 165.0 with an average of 93.2 mg kg⁻¹ soil. Banerjee *et al.* (2009) reported that the bottom soils with less than 200 mg N kg⁻¹ soil in available form may be considered critical for

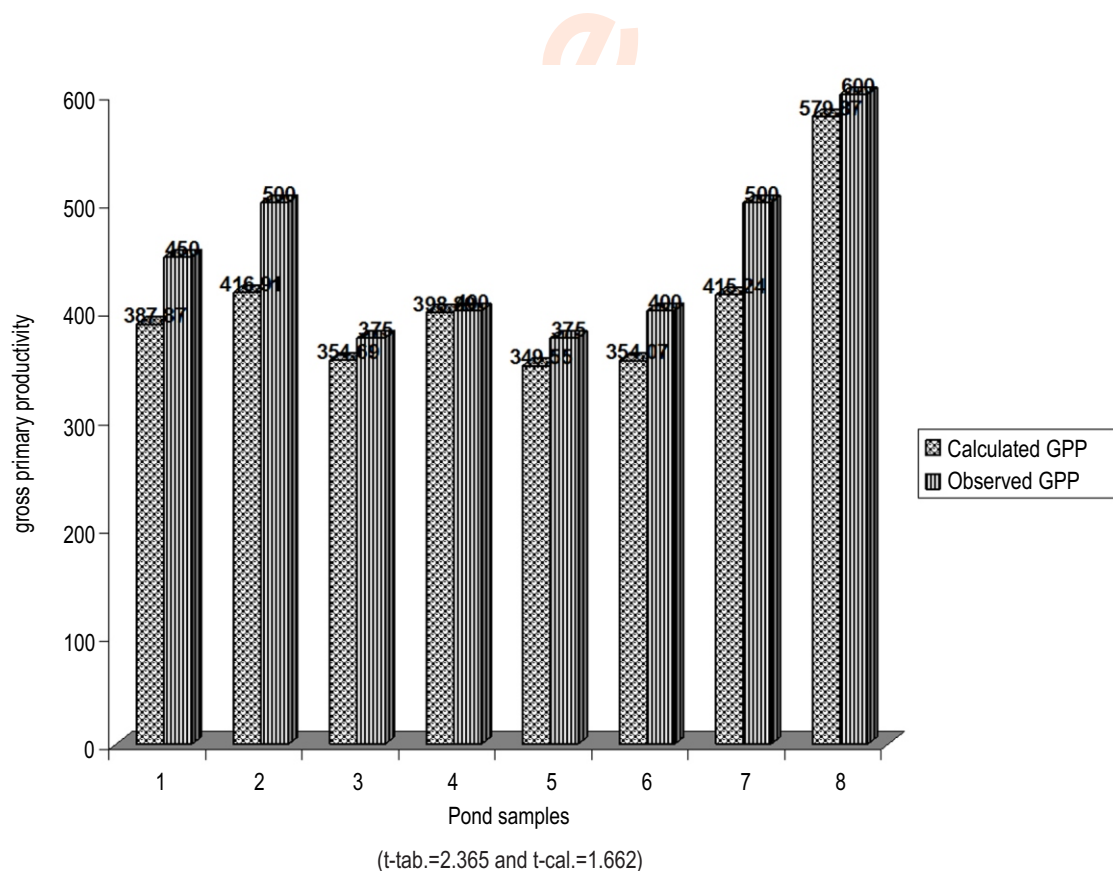


Fig. 2: Observed and calculated gross primary productivity in fish ponds of red and lateritic soil zones.

Table 1: Properties of bottom soils and gross primary productivity (GPP) of water in fish ponds under red and lateritic soil zones

Soil properties	Range	Average
pH	3.3-7.0	5.15
Organic carbon (%)	0.07-1.5	0.78
Available N (mg kg ⁻¹)	21.5-165.0	93.25
Available P (mg kg ⁻¹)	2.55-35.2	18.87
Available K (mg kg ⁻¹)	4.0-286.0	145.0
Available Ca+Mg (mg kg ⁻¹)	54.0-490.0	272.0
Available Zn (mg kg ⁻¹)	0.4-9.9	5.15
Available Cu (mg kg ⁻¹)	1.0-3.9	2.45
Available Fe (mg kg ⁻¹)	1.8-3.1	2.45
Available Mn (mg kg ⁻¹)	9.1-103.4	56.25
Sand (%)	67.5-98.0	82.75
Silt (%)	1.5-19.0	10.25
Clay (%)	0.2-21.5	10.85
GPP of water (mg C m ⁻³ h ⁻¹)	75.0-650.0	362.5

Table 2: Distribution of available plant nutrients in pond soils under study

Soil parameters	Critical level (mg kg ⁻¹)*	Above critical level (%)	Below critical level (%)
N	200	-	100
P	13	50	50
K	80	42.8	57.2

*Banerjee *et al.* (2009).

Table 3: Correlation co-efficients between relevant soil factors and gross primary productivity (GPP)

	pH	K	P	N	GPP
pH		0.5902**	0.6824**	0.6141**	0.8541**
K			0.5506**	0.4184**	0.6539**
P				0.6965**	0.8070**
N					0.6883**

maintaining adequate primary productivity of fish ponds situated under red and lateritic soil zones. In view of their findings, the observed values of available nitrogen in the studied fish pond soils may be considered to be rather poor with all the bottom soil samples exhibiting available nitrogen values below the critical level (Table 2). Since occurrence of nitrogen in any soil environment remains closely related with the organic matter content of that soil (Vass *et al.*, 2017), such low availability of nitrogen in fish pond soils of red and lateritic soil zones may be attributed to the limited occurrence of organic carbon in these pond soils, as discussed above.

Phosphorus is recognized to be the most critical nutrient element in the maintenance of pond productivity. In the present study, available phosphorus values in the fish pond soils of red and lateritic zones ranged between 2.5 and 35.2 mg kg⁻¹ with an average value of 18.85 mg kg⁻¹ soil. Below 13.0 mg of available P

kg⁻¹ soil has been suggested as the index of poor productivity of fish ponds in red and lateritic soil zones by Banerjee *et al.* (2009). In the present study, although the mean availability of phosphorus was marginally above this threshold value, yet 50% of the pond soils appeared to be below this level indicating considerable proportion of these fish ponds to be deficient in available phosphorus. Such low availability of phosphorus in fish pond soils of red and lateritic soil zones due to large scale fixation of phosphorus as Fe and Al phosphate under the prevailing acidic soil conditions has been discussed by Chattopadhyay *et al.* (2003). Despite being the third major nutrient element in pond nutrition, limited research has been done on the potassium dynamics of pond soils (Vass *et al.*, 2015; Boyd, 2018). Wetland soils are considered to be good suppliers of potassium because of their alluvial origin, clayey texture and large scale occurrence of potassium bearing minerals. However, in the present study, the pond soils of red and lateritic soil zones exhibited, in general,

Table 4: Regression analysis of gross primary production on relevant soil properties

$Y = -352.70 + 90.36 \text{pH} + 0.257 \text{K} + 4.311 \text{P} + 0.451 \text{N}$	($R^2 = 0.8415$)	(1) GPP
$Y = -361.79 + 95.768 \text{pH} + 0.250 \text{K} + 5.053 \text{P}$	($R^2 = 0.8361$)	(2) GPP
$Y = -410.18 + 106.588 \text{pH} + 5.581 \text{P}$	($R^2 = 0.8236$)	(3) GPP

GPP = Gross primary productivity of water ($\text{mg C m}^{-3} \text{hr}^{-1}$); N, P, K indicates available status of the respective nutrient elements (mg kg^{-1} soil).

Table 5: Path coefficient analysis of soil factors on gross primary productivity (GPP)

Factors	pH	K	P	N	Corr. with GPP
pH	0.4814	0.0869	0.2211	0.0647	0.8541
K	0.2842	0.1472	0.1784	0.0441	0.5902
P	0.3285	0.0811	0.3240	0.0734	0.5506
N	0.2957	0.0616	0.2256	0.1054	0.6965

Residual = 0.1585; • N, P, K indicates available status of the respective nutrient elements; • Underlined figures indicate the direct effect of the nutrient elements.

comparatively lower values of available potassium than what is commonly observed in most of the fish ponds located in alluvial or other soil zones. This may be due to the occurrence of poor organic carbon, acidic pH, light texture and consequently, low cation exchange capacity in such soils (Sarkar, 2013) which govern the availability of potassium in soils to a great extent. In addition, predominance of low potassium bearing kaolinitic types of clay minerals in red and lateritic soils may also be a major reason for inadequate availability of potassium in such soils (Neogy *et al.*, 1994). Available Ca+Mg values, which helps to maintain the pH of the pond soils and also constitute a source of alkalinity of water, showed a wide range varying from 54.0 to 490.0 mg kg^{-1} soil and this behavior was reflected in the variations in pH values and consequently, the base saturation of the soils.

Among the four micronutrients studied, availability of zinc in the studied pond soils also showed large variation ranging between 0.4 and 9.9 mg kg^{-1} soil with an average value of 5.15. Submerged soils generally tend to reduce the availability of zinc (Mandal and Chattopadhyay, 1992). However, the moderately high status of available zinc in the fish pond soils of red and lateritic soil zones may be due to comparatively lower pH values of these soils which tends to solubilize zinc. Available manganese status of the pond soils was also high with an average of 56.2 mg kg^{-1} . This may be attributed to low pH values of the studied pond soils and also the positive effect of submergence on its solubility. The available copper and iron contents, although comparatively lower than zinc and manganese, showed moderate availability. In general, the studied pond soils exhibited adequate occurrences of these four micronutrient cations in available forms. However, under some specific situations, the high solubility of manganese may appear as a major productivity limiting factor. Use of organic manures is a common practice for increasing the productivity levels of tropical fish ponds. This practice may sometime intensify the reducing condition of the pond bottoms and thereby, enhance the solubility of manganese in such pond soils further, to reach toxic levels.

Textural composition indicated the soils to be lighter in texture, as is the general property of red and lateritic soils (Sehgal, 1998). Apart from influencing many chemical reactions and also the retentivity of different nutrients in pond bottoms, such textural composition may affect the water holding capacity of the studied ponds. Gross primary production in fish ponds is known to be closely related with the yield levels of fishes in various fish culture systems (Downing and Leibold, 2002; Boyd, 2018). To assess the significance of the studied soil properties to pond productivity, these values were correlated with respective gross primary productivity levels of the ponds. The study revealed that out of different soil properties studied, only pH and available N, P and K values of the pond soils were significantly correlated with primary productivity of the ponds (Table 3). Almost similar observations were made by Neogy *et al.* (1994), while carrying out a primary study with limited numbers of fish ponds in the red and lateritic soil zones. Among these properties, the pH levels of the pond soils under this study were predominantly acidic and availability of N, P and K were mostly on lower side. Hence, all these productivity attributing soil factors appeared as the major soil related constraints reducing the primary production of fish ponds located in the red and lateritic soil zones.

Multiple regression analysis (Table 4) clarified that these four soil properties *viz.* pH and available N, P and K contributed to 84.15% variation in gross primary productivity of the studied ponds (Eq.1). Regression analysis following step down method further revealed that among these four soil properties, nitrogen was first deleted from the regression equation (eq. 2) and was followed by potassium (eq. 3), retaining only pH and phosphorus. These two soil properties (pH and available P) together accounted for 82.36% variation in gross primary production of the ponds. None of these two soil factors were deleted further and the prediction efficiency of these two parameters was only marginally lower than the contribution of pH, N, P and K together. Hence, it was concluded that pH and available P were the two most

important components to form the minimum data set of soil factors controlling gross primary productivity levels of fish ponds under red and lateritic soil zones. Of these two factors, BETA x R values revealed that pH contributed to 58.90% and availability of P to 41.10% of variation in GPP of the ponds under study.

Path coefficient analysis was carried out to assess the direct effects of independent variables viz. pH and available N, P and K status of bottom soils on gross primary productivity values of the studied ponds as dependent variable (Table 5). The results of path analysis also revealed that soil pH had the highest direct effect (0.4814) on gross primary production of fish ponds located under red and lateritic soil zones, followed by availability of P (0.3240), K (0.1472) and N (0.1054), respectively. The direct and indirect contributions of pH and P further indicated important role of these two factors in controlling primary productivity levels of the studied ponds. As observed in case of multiple regression analysis, the residual effect of this path coefficient analysis also revealed that these four soil factors were able to explain 84.15% variation in gross primary productions in the fish ponds under study. As stated earlier, the regression eq. 3 (Table 4) on the relationship of minimum data set (MDS) (soil pH and available P) with GPP of pond water appeared to account for most of the variations in GPP as compared to the total effects of soil pH and available N, P and K. An attempt was, therefore, made to assess the efficiency of this equation in predicting the GPP of eight pond water systems of red and lateritic soil zones. These ponds were not included in the first part of the study. GPP values of these pond waters were calculated from the respective soil pH and available P values by using the developed regression equation (3). The calculated values were then compared with the actual GPP under pond condition (Fig. 2).

It was observed that use of the regression model (3) developed by using the MDS of pH and available P values of these pond soils helped to predict the GPP values of water to a precision range of 83.0 to 99.7 % with a mean of 90.6 %. Use of t-test further showed that there was no significant difference between the predicted and the on-pond GPP values. Considering that gross primary production is a major indicator of productivity levels of fish ponds (Olah *et al.*, 1986), the results indicate that there is particular need for proper management of MDS of the identified key productivity attributing soil factors, *i.e.*, pH and available P for improving the yield levels of low productive fish ponds of red and lateritic soil regions. Various aspects of improving the pH levels of acidic pond soils and phosphorus fertilization in fish ponds along with their implications to pond productivity have been discussed by Banerjee and Chattopadhyay (2009a) and Boyd (2018). Adopting these practices are likely to take care of these two key productivity limiting soil constraints of red and lateritic soil regions to increase their yield potentials.

The study concluded that adequate management of four primary productivity limiting soil factors viz. pH and available N, P and K will be helpful to significantly increase the production potentials of low yielding fish ponds located in the red and lateritic

soil zones. Of these four parameters, combined effects of the two key properties viz. pH and available P status of the bottom soils could explain 82.36% variation in gross primary production of these ponds and appeared to be particularly important for managing the natural productivity of the ponds under study. Prediction of GPP using the minimum data set comprising of only these two soil properties showed a mean efficiency level of 90.6%, which appeared to be statistically at par with the on-pond GPP values. In view of the significant importance of this study in simplifying the productivity management of fish ponds through MDS approach, similar investigations are likely to be useful for the fish ponds under other soil conditions also.

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Authors' contribution: **A. Banerjee:** Carried out the study including collection of samples and analysis of relevant properties of soil and water, structured the manuscript; **G.N. Chattopadhyay:** Principal Investigator of the project, supervised the research work and monitored preparation of the manuscript.

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Conflict of interest: The authors declare that there is no conflict of interest.

Data availability: Available from the author as well as the report of the project

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