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### Evaluation of cyanobacterial diversity and rhizosphere soil dynamics in abandoned rice field chronosequences

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#### ABSTRACT

Cyanobacteria are one of the important colonists of the soil rhizosphere. The composition of the cyanobacterial community in the rhizosphere can significantly affect the health of the soil. In this study, comparative changes in the diversity of cyanobacterial populations in abandoned rice fields chronosequences of 4 different age groups (fallow since 2, 4, 6, and 11 years) and paddy rice fields (control group) were investigated. The Shannon diversity index ( $H_s$ ) was observed in the range of 1.076-2.489, which shows increased diversity with time within the chronosequence. Maximum species richness was observed in control followed by 11-year abandoned rice fields. Nostocales were found to be the most prevalent (43%-100%) and dominant order in the abandoned sites. The effectiveness of the soil parameters on the community structure of cyanobacteria and the respective dissemination of the species with them along the abandonment was determined by principal component analysis (PCA). PCA ascertained the maximum variance of organic carbon (OC) and available nitrogen (AN) in the chronosequences. Pearson's product-moment correlations of  $H_s$  with soil OC ( $r = 0.947$ ,  $P < 0.05$ ) and AN ( $r = 0.905$ ,  $P < 0.05$ ) showed significant correlations. The study reveals cyanobacteria's secondary succession over time after abandonment, suggesting potential for sustainable soil reclamation methods.

**Keywords:** Soil biodiversity, Cyanobacterial diversity, Shannon diversity index, Principal component analysis, Species richness

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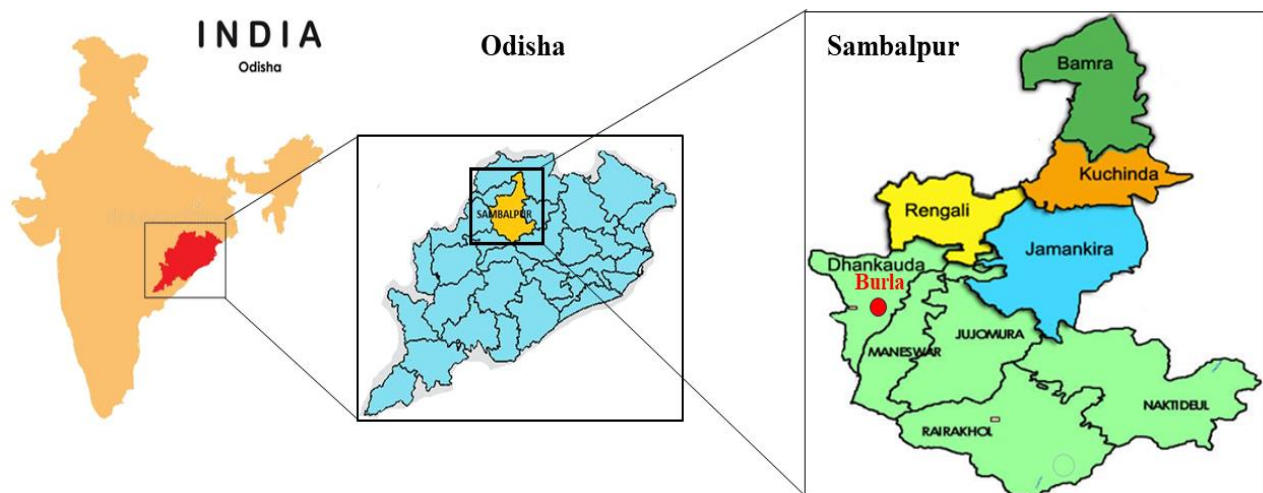
## INTRODUCTION

A large number of abandoned rice fields are ubiquitously seen in different landscapes throughout the world. Evidence shows that intensive agriculture with time significantly decreases soil  $\text{NO}_3^-$ , P, and OC, causing field abandonment (Feng *et al.* 2010; Voronkova *et al.* 2019). Post-abandonment, the fields are rapidly colonized by vegetation through natural succession depending on the severity of the land use before abandonment (Guariguata and Ostertag, 2001). The study of colonization and vegetation dynamics of abandoned agricultural systems plays a crucial role in understanding the secondary succession of lands. It helps us develop successful restoration plans and policies for disturbed agricultural fields (Pickett *et al.* 2013). The soil microbial community dynamics are closely associated with vegetation and several characteristics of soil (Marschner *et al.* 2001; Shanmugam and Kingery, 2018). Microbial inhabitants of soil play a key role in the enhancement of organic matter accumulation, nutrient cycling, and structural stability of the soil (Kumar and Kumar 2022). Cyanobacteria-rich rice fields could be an important target community in such efforts. They are one of the important members which constitute a larger fraction of the soil microflora community. The cyanobacterial communities' shifts have also been found in the secondary succession (Lopez-Lozano *et al.* 2013; Cano-Díaz *et al.* 2022). However, little is known about cyanobacterial diversity responses in a chronosequence of rice fields. The interlinking between the diversity of cyanobacteria and soil attributes in agroecological systems can result in dynamic changes in the biogeochemistry and geomorphology of soil (Sepehr *et al.* 2019; Singh, 2014).

It is significant to monitor the changes in the cyanobacterial community of rice field soils when abandoned due to over-cropping and decreasing order of land fertility. Conservation of abandoned agricultural lands can save deforestation on a large scale. Another major issue with abandoned agricultural lands is that they are vulnerable to gully erosion, which can be prevented (Lesschen *et al.* 2008; Ollobarren *et al.* 2018). In this study, four rice field sites each of which contains several stages of cyanobacterial secondary succession due to the abandonment owing to intensive agricultural practices at different periods in the past (2,4, 6, and 11 years) have been taken for examination. This study evaluates the relationship between the abandonment of cropping and the diversity of cyanobacteria in the rice fields and their subsequent effects on the physico-chemical properties of the rhizosphere soil.

## MATERIALS AND METHODS

*Study sites and soil sampling:* In this study, five types of agriculture field areas were selected. Abandoned agriculture lands with the fallow period of 2, 4, 6, and 11 years were compared with control groups of cultivated paddy fields which were taken as a non-abandonment reference. All these fields were located adjacently. Sampling sites were in Burla, Sambalpur district, Odisha, India, which lies between 21° 28' 43'' north and 83° 51' 55'' east (Figure 1). This area has been tribal-dominated for a long time before the large-scale displacement commenced owing to the construction of the Hirakud dam in 1948 soon after the independence of India. Major cultivation in the study area seems to have commenced after the completion of the dam in 1957. The Indigenous populace depended chiefly on shifting cultivation it can be safely stated that large-scale cultivation took place in the study area after the 1950s. The climate of this area is tropical with a maximum temperature of 47 °C and a minimum of 8.0 °C. Summer is experienced between March to the middle of June while monsoon is witnessed from mid-June through September each year. The lands are chiefly irrigated allowing water to flow from the Hirakud dam. The soil sampling was carried out in July. Samples were collected from the top 10 cm layer of the surface soil in autoclaved polythene bags. Sampling points were located at 5 m intervals along a transect through the fields. Soil collected from respective sites was mixed to form composite samples, sun-dried, and sieved into fine particles before analysis. These were stored in plastic containers, and processed within 10 days of sampling. The maturity of the soil was constantly observed before the present study.





**Figure 1.** Geographical location of sampling sites. The darken zones on the map are enlarged on the side, and the location of sampling site is denoted by a black spot on the map. Burla is situated in Odisha (Sambalpur district), India ( $21^{\circ} 28' 43''$  north,  $83^{\circ} 51' 55''$  east)

*Physico-chemical analysis of soil:* The texture of the soil collected was estimated as per the method of Piper (1950). For the measurement of soil pH, 20 ml distilled water was added to 10 g air-dried soil. The soil-water mixture was agitated for 10 minutes, and the pH of the supernatant was measured (Jackson, 1967). TSS was measured in a conductivity meter. In this method, 40 mL of distilled water was added to 20 g of soil and stirred for 30 minutes. After the settling of the debris, the supernatant was used to rinse the conductivity cell and to fill the electrode bulb avoiding air bubbles, and subsequently, the conductivity was measured. The soil organic carbon (OC) (Walkley and Black, 1934), available nitrogen (AN) (Gupta, 2006), available phosphorous (AP) (Bray and Kurtz, 1945), and available potassium (AK) (Toth and Prince, 1949) were also measured for all the sites.

*Isolation, identification, and diversity of cyanobacteria:* BG 11 medium (Stanier *et al.* 1971) was used to retrieve cyanobacteria from soil samples under laboratory conditions ( $26 \pm 0.5^{\circ}\text{C}$ ;  $7.5 \text{ Wm}^{-2}$  light intensity). The enumeration of cyanobacteria was done by following the MPN (Most Probable Number) technique (Meynell and Meynell, 1965). Cyanobacteria were identified by following the keys of Desikachary (1959). Cyanobacterial abundance ( $D_{BP}$ ) and Shannon diversity index ( $H_s$ ) were determined by using the following equations:

- (i) Abundance (Berger and Parker, 1970)

$$D_{BP} = (N_{max}/N) \times 100$$

Where,  $D_{BP}$  = relative abundance

$N_{max}$  = maximum number of individual cyanobacterial isolates

$N$  = total number of cyanobacterial isolates

(ii) Shannon diversity index (Shannon, 1948)

$$H_s = -\sum (p_i) (\ln p_i)$$

Where,  $H_s$  = Shannon diversity index

$P_i$  = abundance of the  $i^{th}$  species

$\ln$  = logarithm with base 2

*Statistical analysis:* Data related to physicochemical properties of soils are mean  $\pm$  standard deviation (SD) of three independent samples. Data analysis was performed using SPSS 16.0. Bivariate Pearson's product-moment correlations and regression analyses were done between cyanobacterial diversity and various chemical parameters of the soil. The significance of Pearson's correlation coefficients was considered at  $P < 0.05$ . PCA based on Pearson's correlation coefficient was done by using XLSTAT version 2013.2.07. The feasibility of the model for the interpretation of results was tested by the Kaiser-Meyer-Olkin (*KMO*) measure of sampling adequacy. PCA was based on 9 different soil characteristics like sand (%), silt (%), clay (%), pH, TSS (dS/m), OC (%), AN (Kg/ha), AP (Kg/ha) and AK(Kg/ha), which were treated as separate variables.

## RESULTS and DISCUSSION

*Chronological changes of community composition of cyanobacteria in abandoned rice fields:* A total of 49 species were isolated from all sites. Disparity in the distribution of cyanobacteria was observed. The number of species isolated from 2-, 4-, 6- and 11-year abandoned rice fields were 3, 9, 7, and 13 respectively while 17 species were isolated from control rice fields. Table 1 represents the relative presence of cyanobacterial morphotypes in different sampling sites.

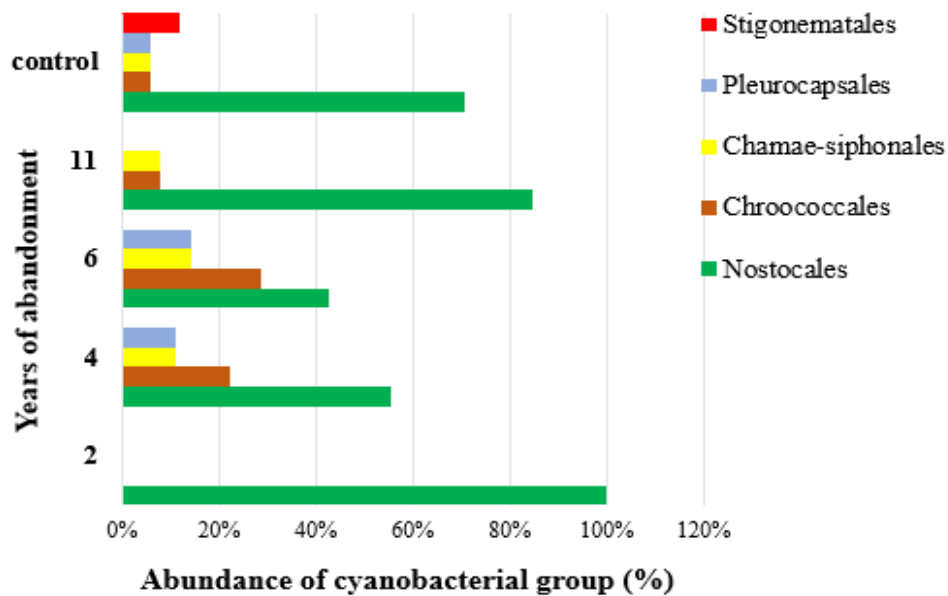
Isolated species were classified and categorized into 5 different orders, viz., Stigonematales, Pleurocapsales, Chamae-siphonales, Chroococcales, and Nostocales respectively. The largest number of the isolated species (22) belong to Nostocales followed by Chroococcales (5) (Table 1). Figure 2 represents the relative distribution of the orders in different fields. All the cyanobacteria found in 2-year abandoned rice field belong to Nostocales (100%). Unlike the 2-year abandoned rice fields, the 4-year abandoned fields harbored 4 different cyanobacterial orders: Nostocales (55.56%), Chroococcales (22.22%), Chamae-siphonales (11.11%), and Pleurocapsales

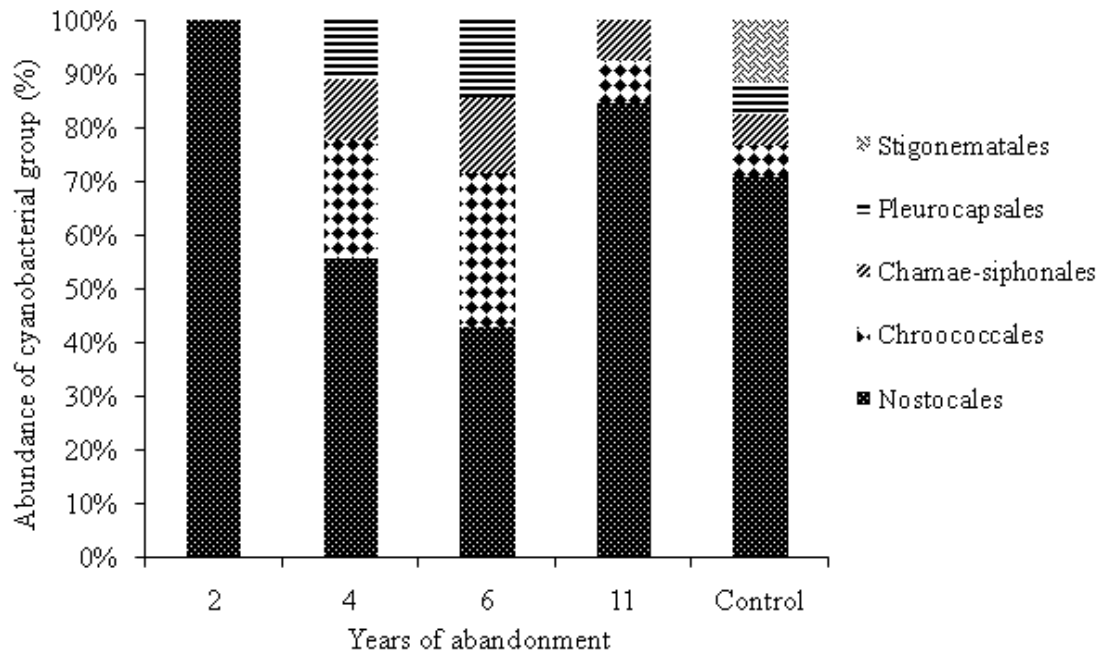
(11.11%). Moreover, in 6-year abandoned rice fields, the percentage distribution of Nostocales (42.86%), Chroococcales (28.58%), Chamae-siphonales (14.28%), and Pleurocapsales (14.28%) was found to vary from the 4-year abandoned soil. On the one hand, Pleurocapsales was absent in 11-year abandoned rice fields and the presence of Nostocales, Chroococcales, and Chamae-siphonales was 84.62, 7.69, and 7.69 % respectively. On the other, all the five orders of cyanobacteria were widespread in control land, i.e., Nostocales (70.60%), Chroococcales (5.88%), Chamae-siphonales (5.88%), Pleurocapsales (5.88%), and Stigonematales (11.76%).

**Table 1.** Relative occurrence of cyanobacteria in abandoned and paddy fields of Burla, Odisha, India

Order	Isolate	Rice fields with fallow period (years)				Paddy fields
		2	4	6	11	control
Chroococcales	<i>Gloeothecae</i> sp.	-	+	-	-	-
	<i>Chroococcus</i> sp.	-	+	+	-	-
	<i>Gloeocapsa</i> sp.	-	-	+	-	-
	<i>Aphanocapsa</i> sp.	-	-	-	+	-
	<i>Aphanothece</i> sp.	-	-	-	-	+
Pleurocapsales	<i>Pleurocapsa</i> sp.	-	+	+	-	+
	<i>Plectonema</i> sp.	-	-	-	-	+
	<i>Anabaena torulosa</i>	+	-	-	+	+
	<i>Nostoc</i> sp.	+	+	-	+	+
	<i>Anabaena</i> sp.	-	+	-	-	-
	<i>Anabaena</i> sp.	-	+	-	-	+
	<i>Nostoc</i> sp.	-	+	-	+	+
Nostocales	<i>Anabaena variabilis</i>	-	+	-	+	-
	<i>Nostoc punctiforme</i>	-	-	+	-	-
	<i>Nostoc linkia</i>	-	-	+	-	-
	<i>Nostoc muscorum</i>	-	-	+	-	-
	<i>Anabaena</i> sp.	-	-	-	+	-
	<i>Nostoc</i> sp.	-	-	-	+	+

	<i>Nodularia</i> sp.	-	-	-	+	-
	<i>Anabaenopsis circularis</i>	-	-	-	+	+
	<i>Nostoc carneum</i>	-	-	-	-	+
	<i>Anabaena cylindrica</i>	-	-	-	-	+
	<i>Aulosira</i> sp.	-	-	-	-	+
	<i>Scytonema</i> sp.	-	-	-	-	+
	<i>Calothrix</i> sp.	+	-	-	+	-
	<i>Gloeotrichia</i> sp.	-	-	-	-	+
	<i>Synechocystis</i> sp.	-	-	-	+	-
	<i>Synechococcus</i> sp.	-	-	-	+	-
Stigonematales	<i>Fischerella</i> sp.	-	-	-	-	+
	<i>Chlorogloeopsis</i> sp.	-	-	-	-	+
Chamae-siphonales	<i>Dermocarpa</i> sp.	-	+	+	+	+





**Figure 2.** Distribution of cyanobacteria in different rice fields

Table 2 shows the relative abundance of cyanobacterial morphotypes (DBP, %), and distribution of diazotrophic/non-diazotrophic cyanobacteria (%) in different abandoned rice fields including the control group. In 2-year abandoned rice fields, three different cyanobacterial morpho-types such as *Calothrix* sp., *Anabaena torulosa*, and *Nostoc* sp. were isolated. All of them are heterocystous and belong to Nostocales order. Out of the three species, *Calothrix* sp. was found to be the most abundant with a relative abundance of 42.55%. However, in 4-year abandoned rice fields *Nostoc* sp. (16.190%) was found as dominant followed by *Anabaena* sp. (15.560%). In this site, 5 out of 9 species were heterocystous. In 6-year abandoned rice fields, *Nostoc punctiforme* was found to be most abundant followed by *Nostoc muscorum* with a relative abundance of 21.02% and 17.520 % respectively. Three species were heterocystous while 4 were non-heterocystous in this site. The most abundant species of 11-year abandoned rice field was *Anabaena torulosa* (13.110%). The number of diazotrophic cyanobacterial species was 9 while 4 were non-diazotrophic in this area. In control land, *Anabaena* sp. (8.36%) was found to be abundant among other morphotypes. Out of 17 cyanobacterial isolates of this site, 13 were found to be heterocystous and 4 non-heterocystous.

*Shannon diversity index:* The Shannon diversity index was used to measure the diversity of cyanobacteria in each field. A steady increase in *Hs* (1.076-2.489) was observed except 4-year

abandoned rice field (Table 2). Control (paddy) rice field has the maximum *Hs* (2.763) followed by 11-year abandoned rice field (2.489). On the contrary, *Hs* was found to be a minimum (1.076) in the 2-year abandoned rice field.

**Table 2.** Diversity and distribution of cyanobacteria in abandoned rice field chronosequences

Years of abandonment	Species	D <sub>BP</sub> (%)	Hs	Heterocystous forms (%)	Non-heterocystous forms (%)
0	<i>Nostoc carneum</i>	7.006			
	<i>Anabaena cylindrica</i>	8.121			
	<i>Nostoc</i> sp.	6.768			
	<i>Anabaenopsis circularis</i>	7.564			
	<i>Nostoc</i> sp.	6.768			
	<i>Aulosira</i> sp.	7.166			
	<i>Anabaena</i> sp.	8.360			
	<i>Nostoc</i> sp.	6.768	2.763	76.47	23.53
	<i>Scytonema</i> sp.	8.121			
	<i>Anabaena torulosa</i>	5.175			
	<i>Fischerella</i> sp.	5.812			
	<i>Gloeotrichia</i> sp.	5.175			
	<i>Chlorogloeopsis</i> sp.	3.503			
	<i>Pleurocapsa</i> sp.	2.389			
	<i>Dermocarpa</i> sp.	6.847			
<i>Plectonema</i> sp.	1.990				
2	<i>Calothrix</i> sp.	42.550			
	<i>Anabaena torulosa</i>	25.530	1.076	100.00	0.00
	<i>Nostoc</i> sp.	31.910			
4	<i>Anabaena</i> sp.	14.290			
	<i>Anabaena</i> sp.	15.560			
	<i>Nostoc</i> sp.	16.190			
	<i>Anabaena variabilis</i>	11.900	2.140	55.56	44.44
	<i>Nostoc</i> sp.	13.170			
	<i>Dermocarpa</i> sp.	7.937			
	<i>Pleurocapsa</i> sp.	6.349			
	<i>Chroococcus</i> sp.	6.667			
<i>Gloeothecae</i> sp.	7.937				
	<i>Nostoc punctiforme</i>	21.020			
	<i>Nostoc linkia</i>	14.010			

6	<i>Nostoc muscorum</i>	17.520	1.910	42.86	57.14
	<i>Dermocarpa</i> sp.	10.190			
	<i>Pleurocapsa</i> sp.	14.970			
	<i>Chroococcus</i> sp.	13.380			
	<i>Gloeocapsa</i> sp.	8.917			
11	<i>Nostoc</i> sp.	7.615			
	<i>Anabaena torulosa</i>	13.110			
	<i>Anabaena</i> sp.	7.740			
	<i>Nostoc</i> sp.	9.363			
	<i>Anabaena variabilis</i>	10.860			
	<i>Nodularia</i> sp.	12.360			
	<i>Calothrix</i> sp.	6.866	2.489	69.23	30.77
	<i>Nostoc</i> sp.	7.740			
	<i>Anabaenopsis circularis</i>	7.491			
	<i>Synechocystis</i> sp.	5.368			
	<i>Dermocarpa</i> sp.	3.620			
<i>Synechococcus</i> sp.	4.120				
<i>Aphanocapsa</i> sp.	3.745				

*Chronological changes of soil physico-chemical variables in abandoned rice fields:* In the present study, the variation of physico-chemical parameters of soils was perceived with abandonment chronology (Table 3). A declining trend in the percentage of sand (86-73.2%) was observed beyond 2-year to 11-year abandoned rice fields. Contrarily, a gradual increase in clay (7.8-11.4%) and silt (6.2-15.4%) contents was seen in the studied area. Positive correlations were observed between clay and silt contents of abandoned paddy field soils and the diversity of cyanobacteria. A similar finding was also observed by Six *et al.* (2006) and Li *et al.* (2017). Both clay and cyanobacteria can promote the formation of larger soil aggregates (Sephehr *et al.* 2019; Wick *et al.* 2009). In control rice fields, the soil was found to be composed of 78.4% sand, 14.5% silt and 7.1% clay. The variation of pH and TSS was marginal in all fields (Table 3).

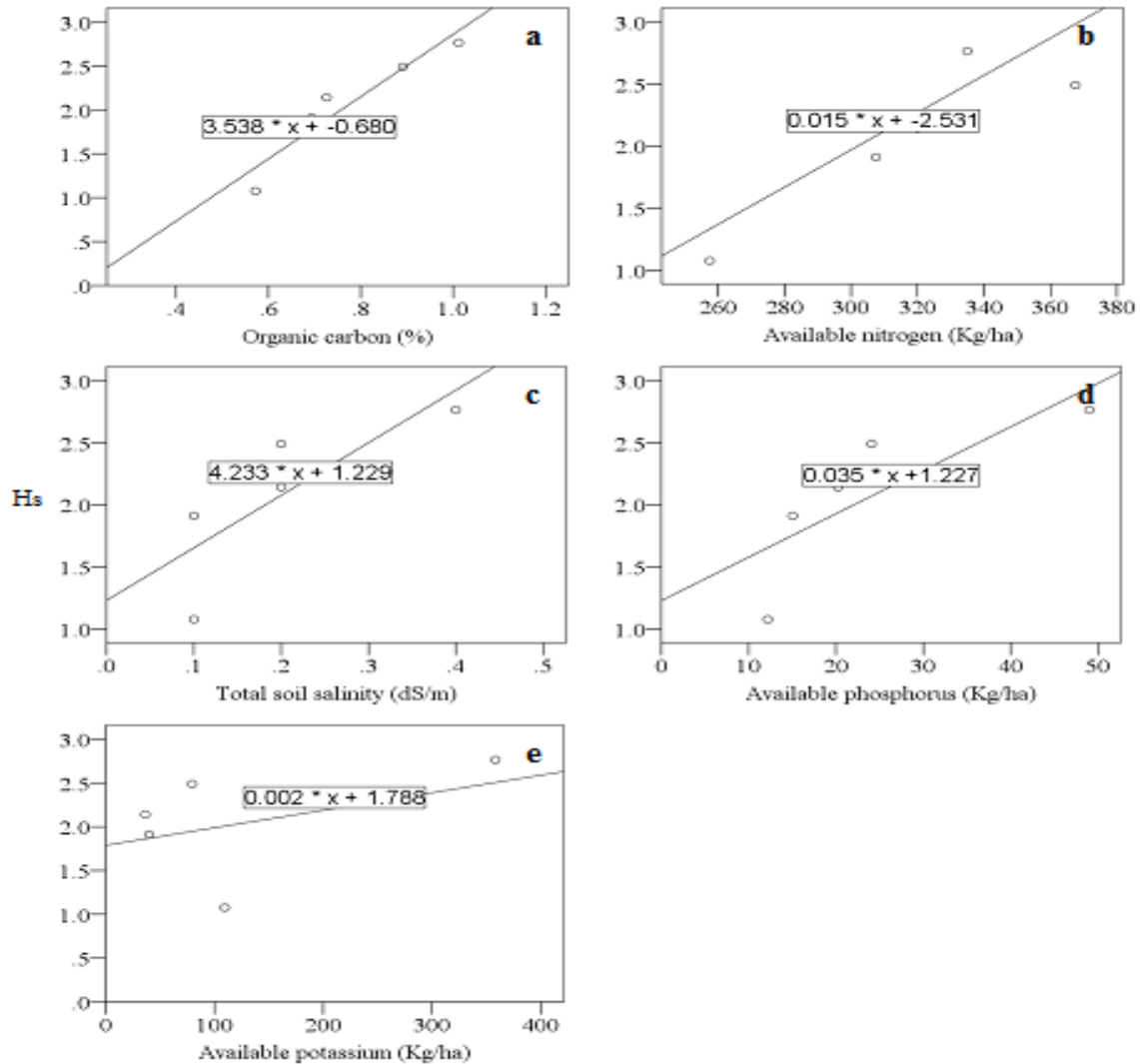
**Table 3.** Physico-chemical analyses of soils of sampling sites

Years of abandonment	Texture (%)			pH	TSS (dS/m)	OC (%)	AN (Kg/ha)	AP (Kg/ha)
	Sand	Silt	Clay					
2	86.00	6.2	7.80	5.7 ± 0.12	0.1 ± 0.01	0.572 ± 0.042	257.5 ± 20.23	12.18 ± 0.97
4	82.08	9.8	8.12	6.3 ± 0.16	0.2 ± 0.01	0.726 ± 0.054	320.0 ± 22.31	20.21 ± 1.13

6	78.00	12.6	9.40	6.0 ± 0.15	0.1 ± 0.01	0.693 ± 0.047	307.5 ± 17.15	15.05 ± 2.01
11	73.20	15.4	11.40	6.8 ± 0.19	0.2 ± 0.01	0.891 ± 0.065	367.5 ± 25.20	24.08 ± 2.85
control	78.40	14.5	7.10	5.6 ± 0.14	0.4 ± 0.02	1.012 ± 0.081	335.0 ± 22.45	49.02 ± 3.53

The pH of the test fields was in the acidic range ( $5.6 \pm 0.14$  to  $6.8 \pm 0.19$ ). The highest pH was  $6.8 \pm 0.19$  observed in 11-year abandoned rice fields while TSS was maximum ( $0.4 \pm 0.02$  dS/m) in control (paddy) rice fields. Soil OC ( $0.572 \pm 0.042$ - $0.891 \pm 0.065\%$ ) was found to be in a gradual increase from the 2-year to 11-year abandoned rice fields except the ones abandoned for 4 years. In the 4-year abandoned rice fields, OC ( $0.726 \pm 0.054\%$ ) was found to be marginally higher than the 6-year abandoned land ( $0.693 \pm 0.047\%$ ). However, maximum OC ( $1.012 \pm 0.081\%$ ) was found in the control (paddy) rice field, which was relatively higher than all the abandoned rice fields. Besides, AN increased ( $257.5 \pm 20.23$ - $367.5 \pm 25.20$  Kg/ha) with increased years of abandonment. The highest AN was  $367.5 \pm 25.20$  Kg/ha found in the 11-year abandoned rice field. A very low profile of soil AP ( $12.18 \pm 0.97$ - $24.08 \pm 2.85$  Kg/ha) was found in abandoned rice fields as compared to control ( $49.02 \pm 3.53$  Kg/ha). Furthermore, the control contained comparatively very high soil AK ( $358.46 \pm 24.31$  Kg/ha) than the abandoned rice fields. The AK was lowest ( $36.51 \pm 1.89$  Kg/ha) in 4-year lands, beyond which there was a relatively small increase in it with the rise of years of abandonment. Relatively higher clay in the abandoned rice field soils elucidates the reason for lower AP in these areas than in the control area. Clay facilitates P absorption on its surface causing a decrease in soil AP. Diazotrophic cyanobacteria facilitate the increase in soil AP (Qiu *et al.* 2023).

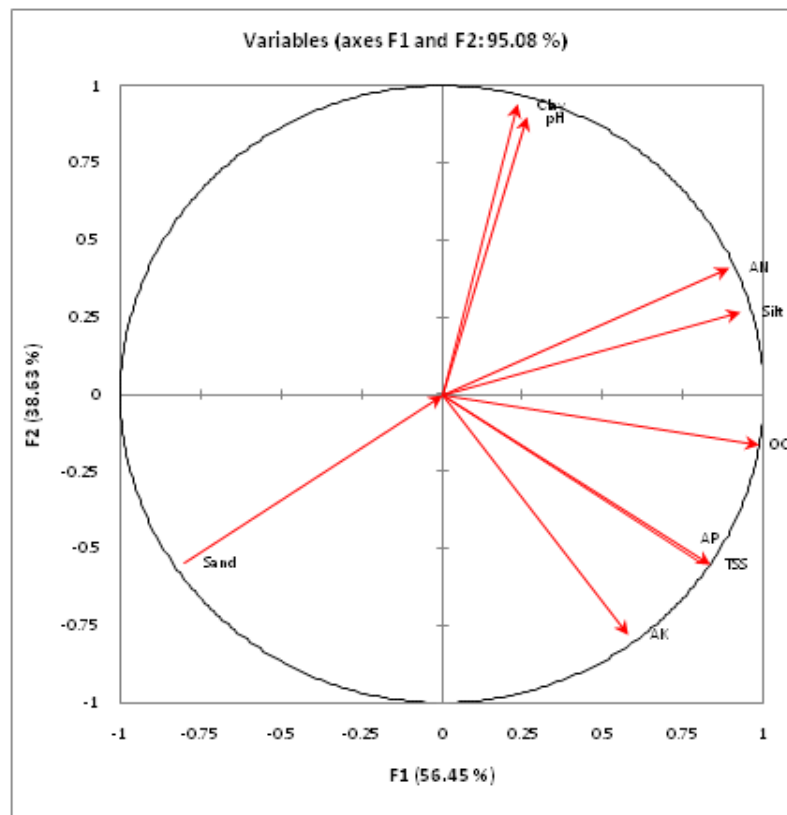
*Correlation between cyanobacterial diversity and different soil attributes:* Correlation analysis of cyanobacterial diversity (*Hs*) and physico-chemical properties (Figure 3) revealed a statistically significant positive correlation ( $r = 0.947$ ,  $P < 0.05$ ) between cyanobacterial diversity (*Hs*) and soil OC (%) (Figure 3a). Besides, the correlation between *Hs* and soil AN (Kg/ha) ( $r = 0.905$ ,  $P < 0.05$ ) was also significant (Figure 3b). In addition, a positive correlation was observed between *Hs* and TSS (dS/m) ( $r = 0.801$ ; Figure 3c), soil AP (Kg/ha) ( $r = 0.798$ ; Figure 3d), and soil AK (Kg/ha) ( $r = 0.477$ ; Figure 3e). However, the above correlations are not found to be significant at 0.05 level. It illustrates the dependence of the rate of carbon accumulation on the rate of nitrogen accumulation as suggested by Knops and Tilman (2000) and Maqubela *et al.* (2009).



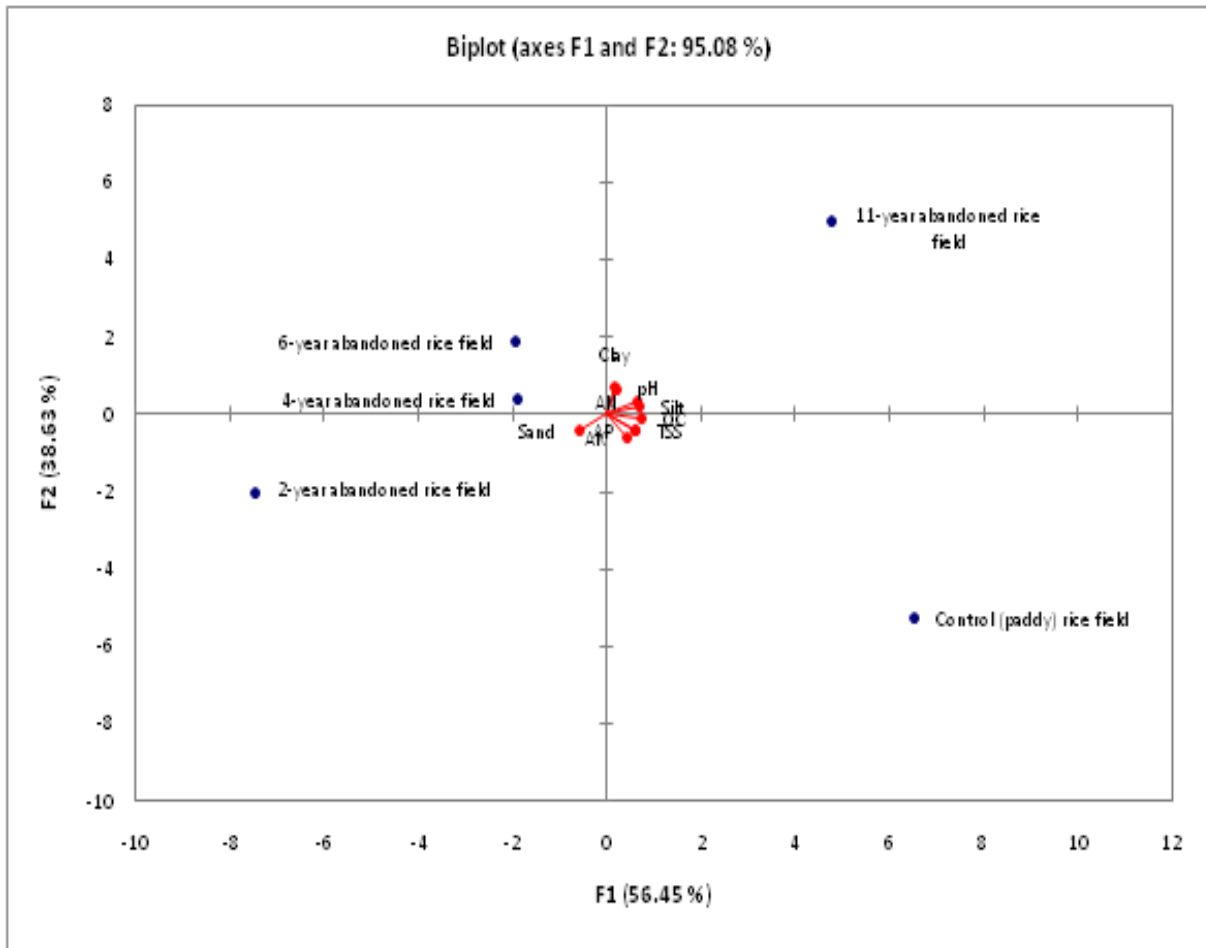
**Figure 3.** Relationship of cyanobacterial diversity ( $H_s$ ) with different soil chemical parameters of 5 different types of fields. **a.** soil OC (%). Coefficient of determination,  $R^2 = 0.897$ ; significant at  $*P < 0.05$  (two-tailed test) **b.** Soil AN (Kg/ha). Coefficient of determination,  $R^2 = 0.819$ ; significant at  $*P < 0.05$  (two-tailed test) **c.** TSS (dS/m). Coefficient of determination,  $R^2 = 0.642$ ; not significant (NS) at  $P < 0.05$  (two-tailed test) **d.** Soil AP (Kg/ha). Coefficient of determination,  $R^2 = 0.637$ ; NS at  $P < 0.05$  (two-tailed test) **e.** Soil AK (Kg/ha). Coefficient of determination,  $R^2 = 0.228$ ; NS at  $P < 0.05$  (two-tailed test)

*Principal component analysis:* PCA was done to trace the rates and trends of variations in the sample space of 2-, 4-, 6- and 11-year abandoned rice fields and control rice fields. The *KMO* measure of sampling adequacy was found to be 0.544, which suggests its feasibility for analysis.

The correlation circle (Figure 4) and PCA biplot (Figure 5) revealed 2 factors (F1 and F2) with 56.45% and 38.63% variability respectively. Thus, the two factors explained a total of 95.08% variability. As is shown in Figure 4, the correlation circle divulged the degree of relationships among the major soil variables based on Pearson's product-moment correlations. The OC (%) was represented by the longest vector, which showed the maximum variance. The biplot (Figure 5) represents the direction of changes occurring with the soil abandonment in terms of vectors. Maximum variations and localization of soil vectors could be observed in between 11-year abandoned rice fields and control rice fields.



**Figure 4.** Correlation circle for unrotated PCA on the physico-chemical properties of soils from 5 different types of fields. Vectors are the loadings on F1 (x-axis) and F2 (y-axis). Variable vectors include sand (%), silt (%), clay (%), pH, TSS (dS/m), OC (%), AN (Kg/ha), AP (Kg/ha), and AK (Kg/ha) (Please refer text for abbreviations)



**Figure 5.** PCA biplot. Samples are represented by dots and the physico-chemical properties of soils by lines. For better visibility, the distance to points is adjusted to 5 in the repositioned labels

The relationship between the diversity of soil cyanobacteria and the restoration of physical and chemical properties of rhizosphere soil under the chronology of cropping abandonment has been explained in this study. The richness of the cyanobacterial community in abandoned rice fields accelerated the restoration of agrological activities with time. Nostocales was found to be the most adaptive and diverse cyanobacterial population in the abandoned rice fields. The interlinking between the diversity of cyanobacteria and soil credited in attaining functional homeostasis of rhizosphere soil of the abandoned rice fields could be a successful restoration strategy for nutrient recycling.

This study suggested that cyanobacteria played important roles in retrieving some crucial nutrients, essential for healthy soil, such as OC and AN. However, the diversity of cyanobacteria

was found to have very little effects on the soil parameters like AK, pH and salinity of abandoned rice fields. Besides, the diversity of cyanobacteria was found dependent on the silt and clay contents of the fields. Thus, it could be beneficial if instead of monoculture, careful selection of mixed culture of cyanobacteria was done for *in situ* algalization in the abandoned rice fields, which can significantly alter the native cyanobacterial diversity. In addition, some other inoculants, which are beneficial and non-competitive to cyanobacterial soil population can also be added to the consortia for inducing sustainable restoration of soil fertility of abandoned croplands.

#### **AUTHORS CONTRIBUTION:**

All authors contribute equally.

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