International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 3 Number 9 (2014) pp. 956-970**
http://www.ijcmas.com

Original Research Article

Microbial biomass Carbon, Nitrogen, and Phosphorus dynamics along a chronosequence of abandoned tropical agroecosystems

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A B S T R A C T

Soil microbial biomass C, N and P were examined along different age series of abandoned agroecosystems (2, 4, 6, 11 and 15 year) to access the impact of land abandonment on soil fertility restoration of tropical agroecosystems. The results showed that the microbial biomass properties (C, N & P) were significantly different ($p<0.05$) along all the sites, depths and months. 15 year fallow land was found to have significantly higher ($p<0.05$) microbial biomass C, N and P than the other fallow land. The microbial biomass C, N and P were in the order of 15yr>11yr>6yr>4yr>2yr. The average microbial biomass C ranged from 59 to 514 µg g-1 soil, microbial biomass N from 14 to 44 µg g-1 soil and microbial biomass P from 8 to 22 µg g-1 soil. The microbial biomass C, N and P showed 88%, 68%, and 63% increase respectively in 15 yr abandoned field over 2 yr abandoned field. In all the fields microbial biomass properties were significantly higher ($p<0.05$) in top soil (0-10 cm) in comparison to soils of 10-20cm and 20-30cm soil depths. Further, highest microbial biomass C, N, and P were recorded in the month of August and lowest in the month of June in all the sites and depths. The ratio of MBC/SOC, MNB/TN and MBP/TP were maximum in 15 year fallow land. Thus, the present study suggested that land abandonment could improve soil fertility of tropical agroecosystems and promote ecosystem restoration.

Keywords

Microbial biomass, tropical agro-ecosystem, soil fertility, ecosystem restoration

Introduction

Clearing of natural forest vegetation for agricultural purpose followed by repeated cultivation, severely affects the production potential of an agroecosystem. Some researchers showed that cultivation of soil previously supporting natural vegetation could lead to considerable losses of soil organic matter and microbial biomass (Tripathy and Singh, 2009). Waldrop et al. (2000) reported that conversion of forest for agricultural purpose decreased microbial biomass and produced compositionally distinct microbial communities. These degraded agroecosystems become unsustainable due to loss of production. Very often these lands become abandoned by the poor farmers of the tropical countries which then undergo a series of directional changes i.e. secondary succession (Bautista-

Cruz and Castillo, 2005). During secondary succession microbial biomass C, N and P along with several soil properties are expected to improve in the abandoned agricultural land. Several literatures have been cited for the changes of microbial community diversity and composition during secondary succession (Broughton and Gross, 2000 and Chabrerie et al. 2003). Zhu et al (2009) marked that changes in plant diversity, composition, and production during succession also influence the microbial community distribution in soil. As per Plassart et al. (2008) microbial activities depend upon the substrate availability in soil.

Soil microbial biomass is an important ecological indicator and acts as a source and sink of available nutrient for plant growth. It is supposed to be an integral part of decomposer subsystem. Soil microorganisms play a crucial role in ecosystem functions (Wardle, 2002; Kirk et al. 2004) such as organic matter decomposition, nutrient cycling, transformation, mineralization etc. It also provides information regarding the organic matter decomposition, nutrient cycling, soil fertility restoration and development of ecosystem function in tropical abandoned agroecosystems. Little change in soil microbial biomass affects directly on ecosystem stability and fertility of soil. Therefore microbiological status is considered as a suitable indicator of soil health during restoration process of degraded agroecosystems. The microbial biomass is a living component of soil organic matter, constituting 1-5% of total organic matter content (Jiang et al. 2009) and it responds more quickly to the changes in soil conditions than SOM (Brookes et al. 2008; Araujo et al. 2010). Any changes in microbial biomass ultimately affect nutrient cycling of soil organic matter. Therefore estimation of microbial biomass can provide useful information on the changes in soil biological properties (Jordan et al. 1995). It has been possible to sense the pace and progress of soil restoration following degradation through the assessment of microbial biomass pool (Harris, 2003). In the present study, we analysed the microbial biomass C, N and P in the abandoned agricultural field under the secondary succession in order to view the soil restoration process if any.

Materials and Methods

Study Site

The study sites were five different abandoned rice fields (abandoned since 2, 4, 6, 11 and 15 year) present in the Sambalpur district of Odisha, India. All the abandoned rice fields were located on the same topographic position and at the bottom of hill, Chandili Dunguri, ½ Km towards south west from Sambalpur University campus at Burla. The study sites are located between latitude 20° 43′N to 20°11′N and longitude 82° 39′E to 82°13′E at 263 m above mean sea level in Sambalpur district of Odisha, India. Before 1950s this area was covered with tropical dry deciduous forest. After the construction of multipurpose hydroelectric Hirakud Dam most of the forest lands were cleared for urbanization and agricultural purpose. Initially the farmers of this locality were adopting conventional methods of agriculture to maximize the crop production. However this method of agricultural practice increased the production of agricultural land for short time period, but later on degraded the soil quality and decreased the crop yield. Very often these derived agroecosystems were abandoned by poor farmers of these areas due to lack of satisfactory crop production. The age of the different abandoned agricultural lands for the present investigation has been ascertained by asking the land owners and interviewing the elderly persons of this locality. The agricultural rice field abandoned since 2007 was referred as 2 year abandoned agricultural field (2yr F), the agricultural rice field abandoned since 2005 referred as 4 year abandoned agricultural field (4yr F), the agricultural rice field abandoned since 2003 referred as 6 year abandoned agricultural field (6yr F), the agricultural rice field abandoned since 1998 referred as 11 year abandoned agricultural field (11yr F) and agricultural rice field abandoned since 1994 referred as 15 year abandoned agricultural field (15yr F). The 11 yr F land covers 1200 sq meters and each of the other four sites covers 900 sq meters. All the sites were lying on the same topography. The 4yr F land was adjacent to the 6yr F land while the 11yr F land was adjacent to the 15yr F land.

The distance between 2yr F land was 100 meters away from 15yr F land. The study area experienced three distinct seasons like rainy (July-September), winter (November-February) and summer (March-June). Relative humidity throughout the year fluctuates from 42.9 percent (during May) to 85.2 percent (during August). Average minimum temperature was found to be 8.9 ºC in the month of January whereas, average maximum temperature was observed to be 42 ºC in the month of May during study period. These areas received average annual rainfall of 166.7 cm, of which 75 percent occurred during the rainy season (July to October). The textural composition of different abandoned rice fields have also been done and the study indicates the soil of 2yr F was sandy loam type where as that of 15yr F was sandy clay loam type. The soils of Sambalpur district belong to mixed red and black soil, red sandy soil, mixed red and yellow lateritic soil (http://www.crida.in/CP-2012/statewiseplans/Orissa%20(Pdf)/OUAT,%20Bhubaneswar/Orissa%20720Sambalpur % 2031.05.2011.p).

Soil Sampling

To study the different soil parameters, random sample of five replicas were taken from three different soil depths (0-10 cm, 10-20 cm and 20-30 cm). Sampling was made bimonthly from August 2009 to June 2010 (one year). The soils were air dried in the laboratory and sieved by the help of 2 mm mesh. The sieved soil samples were analyzed in the laboratory to study the soil physico-chemical properties. The soil moisture content was determined by oven drying the soil at 105 ˚C for 24 hours and expressed in g% (w/w).

Bulk density and water holding capacity were determined following the method prescribed in TSBF hand book (Anderson and Ingram, 1992), soil pH by pH meter using 1:2 (w/v) soil water suspension, the organic carbon content by Walkley and Black's titration method (Walkley and Black, 1934), total nitrogen (TN) by Kjeldhal method (Jackson, 1958), the total phosphorus by Bray and Kurtz (1945). For the microbial biomass properties the fresh soil sample were immediately analysed in the laboratory within one week. The soil microbial biomass carbon (MBC) was determined at bimonthly interval by following chloroform fumigation incubation method of Jenkinson and Powlson (1976). The microbial biomass carbon was estimated by calculating the evolved CO_2-C evolved from fumigated soil minus CO_2-C evolved from un-fumigated soil during 10 days incubation divided by K_c value of 0.45 (Jenkinson and Ladd, 1981). The CO_2 evolved was measured by alkali absorption method. Microbial biomass Nitrogen (MBN) was determined using $CHCl_3$ Fumigation extraction technique as proposed by Brookes et al. (1985). The soil microbial biomass phosphorus was measured by following chloroform fumigation extraction methods of Brookes et al. (1982).

Statistical analysis

The data obtained were subjected to three way ANOVA by using SPSS 17.0 statistical software. Pearson's correlation coefficient was also carried out between different physicochemical parameters and microbial biomass.

Results and Discussion

Soil physiochemical characteristics

The soil physicochemical properties of different land are depicted in the Table 1. All the soil properties in the present study showed maximum value in 15 yr field expect bulk density. The bulk density decreased with increasing fallow period from 2 to 15 yr (1.57-1.32 g cm^{-3}). The soil moisture (%) ranged from 4.49 to 12.17, WHC (%) ranged from 21.77 to 34.84 in the different abandoned fields. pH of the soil was acidic in nature (5.44-6.16). Organic carbon increased from 5.28 to 11.4 mg g^{-1}, TN from 0.60 to1.07 and TP from 23.82 to 256.66 µg g^{-1} soil. Soil of different abandoned fields showed markedly different in their physicochemical properties. The vegetation development on the land affects several soil physicochemical characteristics with the progress of succession (Tscherko et al. 2005). Increase in the age of the land from 2 to 15 year, established different vegetation which led to increase root biomass in soil, increased soil porosity and water holding capacity confirming the findings of Jia et al. (2005). Besides, the dense vegetation cover in 15 year old field was supposed to improve the soil quality in terms of fresh litter input, decline soil erosion and nutrient loss from the ecosystem, thus increased the soil fertility.

Soil Microbial Biomass Carbon (MBC)

Soil microbial biomass carbon in the present study showed significant variation with respect to different soil type. The average amount of MBC at 0-10 cm depth, ranged from 104.5 µg g^{-1}soil in 2 years to 513 µg g^{-1}soil in 15 years, from 81 µg g^{-1}soil to 364 µg g^{-1}soil in 10-20cm, and 58 µg g^{-1}soil to 280 µg g^{-1}soil in 10-20cm depth (Table 3). The MBC showed significant variation ($P<0.001$) with respect to soil depth (Table 4). Comparison of soil MBC across the study sites revealed that the level of MBC showed an increasing trend with respect to land abandonment (Fig. 1). MBC was lower during summer (June) than rainy (August) and it showed maximum value in 15yr F land and minimum in 2yr F land. Seasonal variation in MBC was also significant at $P<0.001$) in all the study sites. The average percentage contribution of soil microbial biomass carbon to organic carbon among the abandoned fields (2, 4, 6, 11 and 15 year) ranged between 1.68-3.84% in 0-10 cm depth, 1.49-3.31% in 10-20 cm and 1.26-2.94% in 20-30 cm soil depth.

Soil Microbial Biomass Nitrogen (MBN)

The microbial biomass nitrogen varied significantly ($p< 0.001$) among seasons, soil depths and stand ages (Table 4). The mean value varied from 19.72 µg g^{-1}soil at surface layer (0-10 cm) to 30.4 µg g^{-1}soil at sub soil (20-30 cm) among all the stands (Table 3). The MBN value was peak during rainy (August) and was least during summer (June) across all stands and in different soil depths. In general the value of MBN was higher in top soil (0-10 cm) than 10-20 and 20-30 cm soil depths in all the study sites. The MBN (Fig. 2) also showed significant increase with increase in stand age and minimum value was noticed in recent abandoned fields (2yr F) and maximum in15yr F. Similar to MBC, the average percentage contribution microbial biomass nitrogen to total nitrogen among the abandoned fields were 2.97, 3.04, 3.11, 3.25 and 3.65 in 0-10 cm soil layer, 2.75, 2.84, 3, 3.1 and 3.5 in 10-20 cm, 2.64, 2.75, 2.81, 2.93 and 3.25 in 2, 4, 6, 11 and 15 year abandoned rice fields respectively.

Soil Microbial Biomass Phosphorus (MBP)

MBP (Fig. 3) significantly differed (P<0.001) between different fallow lands (Table 4). The values in 2yr F land were 12.29, 9.74 and 8.26 µg g^{-1}soil in 0-10 cm, 10-20 cm and 20-30 cm soil depths respectively, which were significantly lower than that of other fallow lands. Highest microbial biomass phosphorus content (Table 3) was recorded in the 15yr F land (21.27, 18.63 and 17.14 µg g^{-1}soil in 0-10 cm, 10-20 cm, and 20-30 cm soil depth respectively). MBP significantly declined down the soil profile in all abandoned fields. Seasonal variation of MBP (P<0.001) showed a higher value in rainy season (August) and lower value in summer (June). The average microbial biomass phosphorus as percentage of total phosphorus were found to be 5.01, 5.8, 6.77, 7.24 and 7.83 in 0-10 cm soil depth, 4.65, 5.69, 6.64, 7.11 and 7.98 in 10-20 cm and 4.35, 5.61, 6.51, 6.93 and 7.89 in 20-30 cm soil layer along the chronosequence of abandoned fields.

Fertility status of soil is influenced by microbial biomass sustained per unit soil organic carbon. Therefore especially microbial biomass C, N & P are used as sensitive indicator for evaluation of soil fertility. The gradual increase in soil microbial biomass carbon, nitrogen and phosphorus with the increase in fallow period implies the improvement of soil fertility status through secondary succession. Three way ANOVA (Table 4) revealed significant effect of sampling season, sampling depth, and fallow period on MBC, MBN, MBP, and the ratios of MBC/OC, MBN/ TN, MBP/ TP, and MBC/MBN at p < 0.001. The two way interactions between fallow period and soil depth, fallow period and season, season and depth were also significant at p< 0.001for all the microbial characteristics and different ratios. Wide range of ratios of microbial nutrients to total soil nutrients in later stages of succession of the present study indicated more nutrient immobilization into the microbial nutrient pool.

Haripal and Sahoo (2013) reported that different enzyme activities like amylase, cellulase, dehydrogenase, phosphatase and urease secreted by different microorganisms increased with increase of fallow period. Analysis of correlation coefficient between MBC, MBN, MBP, soil moisture, water holding capacity, pH, OC, TN and TP and the different enzyme activities (Haripal and Saho, 2013) (Table 2) revealed significant positive correlation between microbial biomass C, N and P (p<0.01) with soil moisture, water holding capacity, pH, OC, TN, TP, amylase, cellulose, dehydrogenase, phosphatase, urease and negative correlation with bulk density.

The microbial biomass C, N and P indicate significant difference among the abandoned fallow lands. The microbial biomasses were significantly lower in younger field (2yr F) than older field (15yr F). This suggests that land abandonment had positive effect on soil microbial biomass build up. Increase in the size of microbial biomass with progress of land abandonment was supposed to be due to substrate input from vegetation compartment that are developed during secondary succession in the abandoned fields. The vegetation cover, plant species and soil organic matter are important driver of microbial biomass changes during succession (Yao et al. 2000 and Tscherko et al. 2005). Change in vegetation types may be related to differences in quality and quantity of organic matter input through various litter and root type decomposition which act as a energy source for organism (Dlamini, 2002) in soil and thereby, influence the soil microbial biomass (Feng et al. 2009 and Jin et al. 2010). Decrease in SOC causes decrease in soil microbial biomass (Chen et al. 2005). Thus, higher microbial biomass C, N and P in older fields indicates higher organic matter build up during the secondary succession. This is evident from the positive relationship of microbial biomass C, N and P with soil organic carbon, which is in agreement with the findings of Wang and Wang (2007). Besides, the development of vegetation canopy cover check the soil moisture content on the surface soil and provide favorable environment for microbial growth and activity (Gliessman, 1989) by declining heat stress, soil dryness and disturbance.

Seasonal variation of soil microbial biomass C, N and P was significantly higher during the month of August (rainy season) and lower in the month June (summer season) along all the study sites. An increase of soil microbial biomass results in immobilization of nutrients, whereas decrease in microbial biomass results in mineralization of nutrients (Yang et al. 2010). Thus the higher microbial biomass in the month of August (Rainy season) in the present study was due to higher immobilization of soil nutrients by the microbes during the decomposition of organic matter. Besides, soil moisture showed a close relation with the microbial biomass (Patel et al. 2010 and Yang et al. 2010), which favours the growth of microbes and fungi (Acea and Carballas, 1990) during this season. Several authors (Lynch and Panting, 1982; Santruckova, 1992) also reported higher microbial biomass in wet conditions.

The soil microbial biomass significantly decreased with increase in soil depth. This might be due to decrease of soil organic carbon content with increased soil depth. The soil microbial biomass is very sensitive to little change in organic matter content of soil, which directly serves as an energy source. Chen et al. (2005) and Wang and Wang (2007) reported a linear correlation between TOC and soil microbial biomass. Franzluebbers et al. (1994) also reported higher microbial biomass in upper soil layer.

The MBC/SOC represents the available of substrate and quantity of SOC immobilized in microbial biomass cell (Garcia et al. 2002). The greater contribution of microbial biomass C, N and P to soil nutrient pool in an ecosystem represent the greater availability of nutrient which is observed in the 15 yr fallow land and least in recent fallow land. Though it is expected that MBC/SOC ratio decreases with soil age, but several authors reported increased use of recalcitrant carbon pool in soil in different conditions. Biasi et al (2005) reported that microorganisms are able to utilize more stable, recalcitrant C pools, when labile soil carbon pools will be depleted due to increasing temperatures. Sainju and Lenssen (2011) opined that greater MBC/SOC ratios in CA (continuous alfalfa cropping) and D-P/B (durum-Austrian winter pea (Pisum sativum L.)/barley mixture hay (D-P/B) cropping) were probably related to lower C/N ratio of root biomass (21.0 and 27.4, respectively) that may have promoted microbial biomass and activity in these treatments. As per Torres et al. (2005), Paul and Clark (1996), Carranza et al. (2012), the time since residue deposition, and the climatic conditions which modified the microbial activity may be responsible in the proportion of labile and recalcitrant soil carbon which ultimately decides the MBC/SOC ratio. Further Craine and Wedin (2002) and Zak et al. (2003) noticed that increased plant diversity has been shown to increase soil respiration and microbial biomass because of increased net primary productivity (and therefore greater C inputs that may be immobilized by microbs). Thus increase in plant diversity, favourable soil moisture and temperature probably caused the depletion of labile soil carbon pool thereby forcing the microorganisms to use the recalcitrant carbon pool which have resulted in the increase in MBC/SOC ratio in the older abandoned field in our study.

The present investigation also revealed that the contribution of MBC to organic carbon was within the range of 1.5-5.3% as reported by Luizao et al. (1992) for tropical soil. Similarly the percentage contribution of microbial biomass N to total soil N (2.64-3.68%) was within the range of 3.4-5.9% observed by Martikainen and Palojarvi (1990) for forest soil, and the contribution of microbial biomass P to total P in the present study was 2.99-10.21% which was at par with the findings of Maithani et al. (1996) for subtropical humid forest (2.4-7.9%) and Brookes et al. (1984) for tropical arable land (1.4-3.5%). The proportion of microbial biomass C, N and P increased with the progress of the period of abandonment which indicates higher microbial biomass carbon per unit soil organic carbon and greater channelization of soil nutrients in to soil microbial compartment during secondary succession.

The microbial quotient (MBC/MBN) represents the status of microbial community in soil. It has been reported that, higher value of MBC/MBN showed fungal dominated microbial community and lower value showed bacterial dominated microbial community in the soil ecosystem (Campbell et al. 1991). Present study revealed an increasing trend of MBC/MBN ratio with increase in the age of abandoned land which indicates the establishment of fungal dominated microbial community during the secondary succession. The ratio of MBC/MBN (4.14-11.7) was close to the finding of Maithani et al. (1996) and Moore et al. (2000). Usually fungal dominated microbial community is equated with relatively more nutrient conservation mechanism in tropical soil (van der Wal et al. 2006). The ratio of MBC/MBP indicates the available of P in soil (Dilly et al. 1997). Narrow microbial C/P ratio reflects enriched microbial biomass P in soil where as wide ratio reflect more immobilization of P content in soil. The microbial Biomass C/P ratio in the present study (2.99-10.21) was very low as compared to finding of Brookes et al. (1984) which was 47:1 for global grass land average which indicates high Phosphorus content that are locked up in microbial biomass. This indicates that during secondary succession the growing microorganism populations convert inorganic forms to organic phosphate, which are then incorporated into their living cells.

The significant correlation ($p<0.01$) between MBC and MBN, MBC and MBP, microbial biomass C, N and P with soil organic carbon, nitrogen, phosphorus, soil moisture, pH, water holding capacity are in agreement with the finding of Sharma et al. (2004) and Patel et al. (2010). The correlations between microbial biomass C, N and P with organic carbon, total nitrogen and total phosphorus and enzyme activities showed a gradual build up of microbial biomass during the secondary succession along the chronosequence of abandoned fields. Thus development of vegetation cover during secondary succession provides favorable microclimate, organic matter content which accumulates more carbon in microbial biomass.

Table.1 Soil physico-chemical properties in the different abandoned rice agro-ecosystems (values are average of three soil depths)

Parameters	2 yr	4 yr	6 yr	11 yr	15 yr
SM (%)	4.49±0.82	5.74±0.9	7.05±1.02	8.68±0.8	12.17±1.8
BD (g cm^{-3})	1.57±0.04	1.52±0.04	1.47±0.05	1.41±0.06	1.32±0.07
WHC (%)	21.77±2.29	24.48±2.43	26.98±3.24	30.05±2.2	34.84±1.79
pH	5.44±0.11	5.67±0.19	5.86±0.31	6.08±0.41	6.16±0.38
SOC (mg g^{-1})	5.28±0.97	5.34±0.89	7.45±1.34	9.82±1.65	11.42±1.93
TN (mg g^{-1})	0.60±0.06	0.65±0.08	0.84±0.09	0.99±0.09	1.07±0.12
TP (µg g^{-1})	223.82±28.29	233.72±29.92	241.88±31.81	248.72±32.51	256.66±33.59

Table.2 Microbial biomass C, N and P (µg g^{-1}) and their contribution (%) to the soil organic-C, soil N and soil P in different age series of abandoned rice fields

Age	Soil Depth (cm)	MBC	MBN	MBP	MBC/ SOC	MBN/TN	MBP/TP	MBC/MBN	MBC/MBP
2 yr	0-10	104.51	19.73	12.30	1.69	2.97	4.83	5.30	2.44
	10-20	81.05	16.77	9.74	1.49	2.75	3.66	4.83	3.28
	20-30	58.94	14.22	8.26	1.39	2.64	2.99	4.14	4.68
4 yr	0-10	155.36	22.46	14.93	2.45	3.02	5.27	6.92	1.82
	10-20	115.41	18.29	11.95	2.30	2.85	4.07	6.31	2.54
	20-30	84.98	15.82	10.64	1.83	2.74	4.88	5.37	2.57
6 yr	0-10	274.16	28.62	17.72	3.15	3.12	7.76	9.58	0.83
	10-20	220.36	25.95	14.96	2.89	3.00	6.31	8.49	1.08
	20-30	158.00	20.38	13.15	2.62	2.80	5.39	7.75	1.54
11 yr	0-10	398.98	35.33	19.35	3.47	3.24	7.76	11.29	0.62
	10-20	290.47	30.50	16.30	2.97	3.11	8.20	9.52	0.68
	20-30	214.39	26.21	14.33	2.62	2.92	6.93	8.18	0.96
15 yr	0-10	513.79	43.92	21.72	3.82	3.68	10.21	11.70	0.41
	10-20	364.24	37.46	18.64	3.24	3.49	8.51	9.72	0.60
	20-30	280.03	30.40	17.15	2.93	3.25	7.54	9.21	0.81

Table.4 Results of three-factors ANOVA (year of abandonment, soil depth & month) for microbial biomass (*p<0.05, **p<0.01, ***p<0.001))

Factors (F-Ratio)	MBC	MBN	MBP	MBC/OC	MBP/TP	MBN/TP	MBC/MBN
year	543.10*	1744.13*	1814.11*	201.5***	636.3***	85.06***	387.9***
depth	2220.57*	760.27*	604.7*	53.9***	12.5***	55.2***	122.8***
month	991.95*	543.22*	1361.33*	51.3***	1203**	1.055	95.***
year × depth	501.49*	21.57*	1.51*	1.832	2.5***	0.509	4.5***
year × month	74.95*	13.63*	27.29*	5.039***	14.17***	0.567	8.4***
depth × month	25.65*	10.04*	848.05*	5.011***	435.08***	0.547	7.6***
year × depth × month	18.04*	1.35*	8.25*	0.935	3.736***	0.510	1.864***

Fig.1 Soil microbial biomass carbon (µg g^{-1} soil) along the chronosequenced abandoned agroecosystems with respect to soil depth and months (mean±SD).

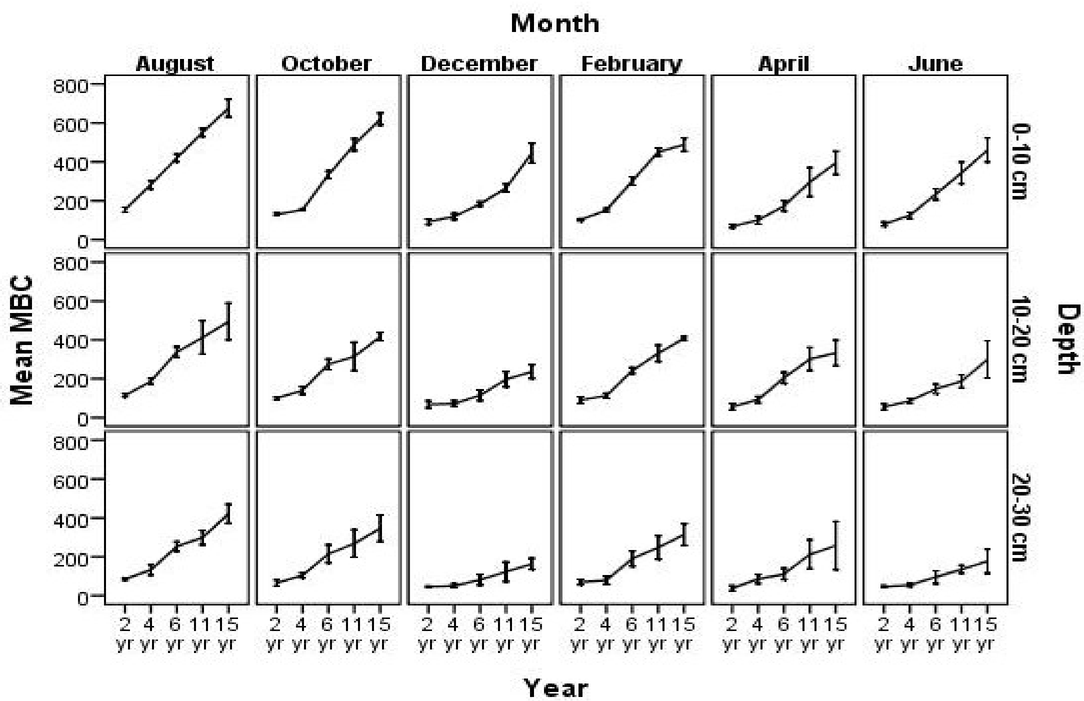


Table.2 Pearson correlation coefficient among soil physicochemical, microbiological and biochemical properties

	SM	WHC	BD	pH	OC	TN	TP	MBC	MBN	MBP	MBC/OC	MBP/TP	MBN/TN	AMY	CEL	DHE	PHO	URE
SM	1																	
WHC	0.456**	1																
BD	-0.349**	-0.719**	1															
pH	0.416**	0.550**	-0.520**	1														
OC	0.859**	0.582**	-0.528**	0.528**	1													
TN	0.862**	0.557**	-0.470**	0.497**	0.967**	1												
TP	0.646**	0.152*	0.004	0.110	0.641**	0.716**	1											
MBC	0.854**	0.606**	-0.540**	0.617**	0.913**	0.897**	0.504**	1										
MBN	0.864**	0.622**	-0.581**	0.547**	0.959**	0.963**	0.616**	0.933**	1									
MBP	0.619**	0.456**	-0.377**	0.345**	0.671**	0.669**	0.601**	0.599**	0.662**	1								
MBC/OC	0.553**	0.486**	-0.423**	0.599**	0.526**	0.532**	0.155*	0.779**	0.597**	0.343**	1							
MBP/TP	0.022	0.302**	-0.383**	0.228**	0.050	-0.019	-0.322**	0.111	0.068	0.539**	0.210**	1						
MBN/TN	0.509**	0.584**	-0.663**	0.485**	0.552**	0.498**	0.113	0.645**	0.700**	0.413**	0.577**	0.313**	1					
AMY	0.867**	0.553**	-0.474**	0.515**	0.871**	0.858**	0.547**	0.887**	0.877**	0.670**	0.614**	0.170**	0.586**	1				
CEL	0.837**	0.596**	-0.607**	0.487**	0.838**	0.819**	0.479**	0.834**	0.854**	0.690**	0.616**	0.287**	0.646**	0.890**	1			
DHE	0.825**	0.547**	-0.446**	0.406**	0.824**	0.815**	0.564**	0.763**	0.806**	0.726**	0.449**	0.217**	0.486**	0.868**	0.860**	1		
PHO	0.851**	0.649**	-0.594**	0.536**	0.934**	0.917**	0.551**	0.889**	0.941**	0.716**	0.565**	0.183**	0.631**	0.879**	0.866**	0.871**	1	
URE	0.894**	0.571**	-0.529**	0.496**	0.869**	0.848**	0.480**	0.884**	0.880**	0.694**	0.642**	0.278**	0.628**	0.922**	0.930**	0.878**	0.899**	1

Fig.2 Soil microbial biomass nitrogen (µg g^{-1} soil) along the chronosequenced abandoned agroecosystems with respect to soil depth and months (mean±SD).

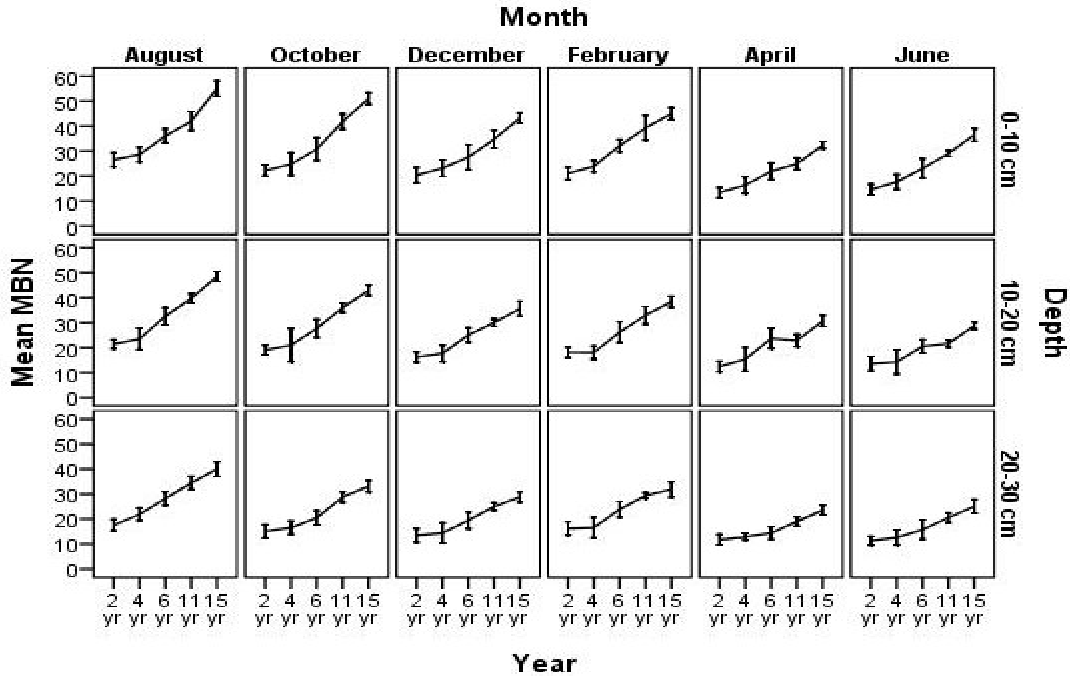
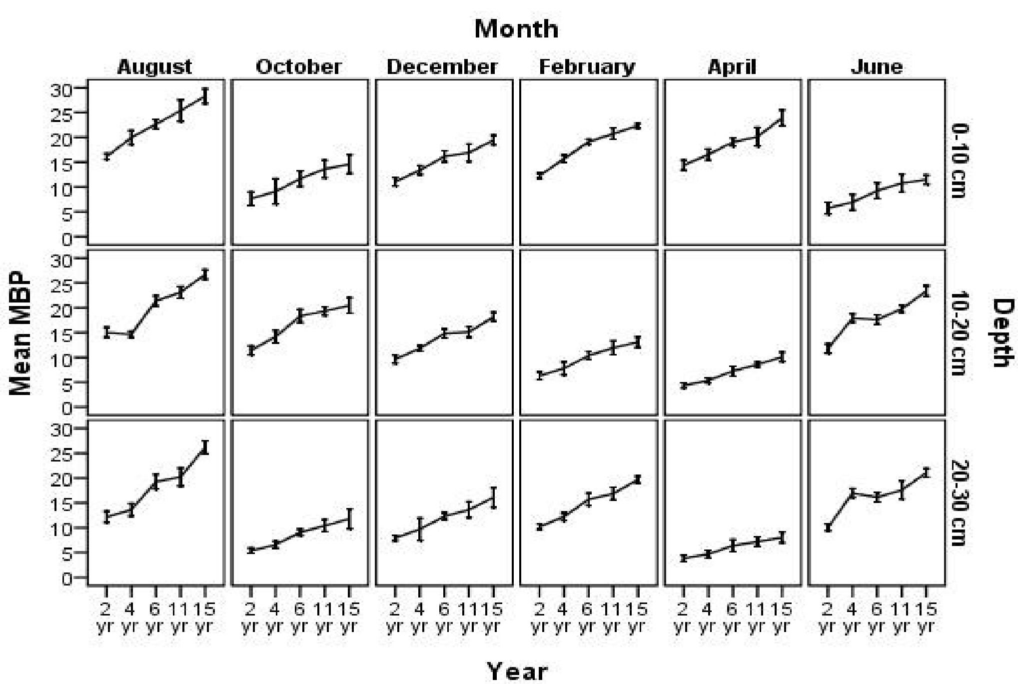


Fig.3 Soil microbial biomass phosphorous (µg g^{-1} soil) along the chronosequenced abandoned agroecosystems with respect to soil depth and months (mean±SD).



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