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Long-term lowland rice and arable cropping effects on carbon and nitrogen status of some semi-arid tropical soils

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Samples of surface (0–30 cm) soils were collected from eight sites in the semi-arid tropical regions of India to evaluate and compare the long-term effects of lowland rice or paddy and non-rice or arable systems on soil organic C (SOC), soil inorganic C (SIC) and total N status. The results showed that soil samples from sites under lowland rice double cropping system had greater organic C and total N content than those from soils under rice in rotation with upland crop or under other arable systems. The SOC : N ratio was wider in soil samples from sites under lowland rice compared to those under other arable systems, which had lower C : N ratios. Samples from soils under lowland rice system tended to have a narrower SIC : N ratio than those under arable systems, indicating a better pedo-environment under paddy rice. Our results support earlier findings that sites under continuous wetland rice cropping accumulate organic matter and contain higher soil organic matter compared to the sites under other arable systems.

Keywords: Arable systems, lowland rice, natural vegetation, nitrogen, pedoenvironment.

MAINTENANCE of fertility in soils of the tropics and semi-arid tropics (SAT), a prerequisite for sustainable increase in agricultural productivity, is a major challenge to farmers and researchers alike. Soils, especially those in the SAT are low in organic matter and nutrient reserves. High temperature in the tropics, which results in rapid decomposition and loss of organic matter, is the primary cause of the low organic matter status of soils. Moreover, under dryland agriculture, application of nutrients and organic matter through external inputs is generally low due to socio-economic conditions of the farmers and other factors. Under low or no external input management practices, agricultural productivity depends on the inherent fertility of soils, which is generally low[1].

Jenny and Raychaudhari[2] studied the effect of climate and cultivation on the nitrogen (N) and organic matter reserves in Indian soils. The approach used was based on collection of soil samples across the country from cultivated fields and forested soils in relation to a climatic grid in which mean annual temperature and mean annual precipitation appeared as independent variables. Based on the analysis of 500 soil samples for organic carbon (C) and total N across India, these authors showed that the climatic effects on soil organic matter and N status are pronounced. Soil N and C increased with increasing mean annual precipitation and decreased with increasing mean annual temperature. Soils in the drier regions had low reserves of organic matter and N compared to those in the humid and sub-humid zones of the country[2].

Velayutham *et al*.[3] and Bhattacharyya *et al*.[4] carried out studies on carbon stocks in Indian soils. Analysis of thousands of soil samples in the course of these studies helped prioritize research on C sequestration potential in soils of the SAT regions in India. Recently, the concept of quasi-equilibrium values of soil organic C relative to organic C status of forest soils as reference or control has been found

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useful[5] for determining the scope and potential of SAT soils to sequester C.

Equally important is the finding that soils under paddy or lowland rice cultivation generally have greater organic C and N than those under other arable cropping systems. For example, analysis of soil samples from 71 sites under lowland rice cultivation in the country showed that sites under paddy contained either equal or more, but seldom less, N and C than those under non-rice cropping sites. Moreover, rice soils had much higher (50% or more) cultivation index (N or organic C of cultivated soil divided by N or organic C of virgin soil, multiplied by 100) than soils under arable cropping. The authors concluded that the low level of organic matter in many Indian soils is primarily caused by the environment, and also by cultural practices[2].

The findings of Jenny and Raychaudhari[2] on relatively high organic matter status of wetland rice soils are in accordance with those recently reported by Sahrawat[6], based on a detailed review of global literature on the accumulation of organic matter in submerged soils and sediments. The review of recent literature demonstrated that organic matter preferentially accumulates in soils that remain submerged for prolonged period. Accumulation of organic matter and C sequestration has also been reported to be significant in double-cropped lowland rice (rice–rice) even during relatively short-term experiments. Inclusion of an upland crop in the crop sequence with lowland rice system has been found to result in decreased organic C and total N due to low C sequestration in soils[7].

The mechanisms involved in preferential accumulation of organic matter in wetland soils are ascribed mainly to anaerobiosis and the associated chemical and biochemical changes that take place in submerged soils following their prolonged flooding under water. For example, decomposition of soil or added organic matter is relatively fast, complete and efficient in soils under aerobic condition, where oxygen is the electron acceptor. However, decomposition of organic matter in the absence of oxygen in submerged or anaerobic soils is comparatively slow, incomplete and inefficient. In addition, in submerged soils the formation of recalcitrant complexes with organic matter renders them less available for microbial attack; biological nitrogen fixation coupled with overall higher primary productivity of wetlands and decreased humification of organic matter lead to net accumulation of organic matter in wetland soils and sediments[6].

Accumulation of organic matter under submerged conditions is the basis of maintenance of organic matter and fertility in wetland rice soils compared to their arable counterparts[6,8]. Obviously, there is a need to further test this hypothesis for soils in the SAT regions of India. The objective of this communication therefore, is to determine and compare soil organic C (SOC), soil inorganic C (SIC), total C (TC) and N status of sites under wetland rice and other arable cropping systems under a range of climatic and cropping systems in India. The present study aims to provide additional evidence on soil organic matter status as affected by lowland rice and other arable systems. Additionally, the study examines the influence of lowland vs arable systems on the dynamics of SOC, SIC and total N ratios, which are of critical importance in the maintenance of fertility and pedoenvironment[9].

The sites were selected from benchmark locations representing soils under a range of different land-use systems. The sites selected represented soil series covering large areas and captured the diversity of land-use systems prevalent in the region, including lowland rice and arable cropping systems. The sites have been under the specified systems for 20 years or more[5] and apparently represent quasi-equilibrium values of soil organic C and N.

Background information about the sites, including location, soil classification, mean annual rainfall, mean annual temperature, bioclimatic zone, land-use systems and data on management practices is provided in Tables 1 and 2. In addition to various cropping systems, management levels also varied across the sites. High management (HM) refers to applications of major nutrients (N, P and K) at higher rates plus regular application of manure, incorporation of crop residues and inclusion of cropping systems involving growing of legumes under soil conservation practices as a part of the improved systems[1]. Low management (LM) or farmers' management (FM) refers to applications of the major nutrients (N, P and K) at lower rates, with little or no applications of manure, returning of crop residues and growing the cereal as sole crop or cereal-based system without implementing soil moisture conservation practices[1,10].

Surface soil samples (0–30 cm) selected for this study were from eight benchmark sites. The soil samples were air-dried and ground to pass through a 2 mm sieve before analysis. For organic C and total N determination, soil samples were ground to pass through a 0.5 mm sieve. Soil pH was measured with a glass electrode using a soil to water ratio of 1 : 2 (w : v). Soil organic C was analysed following the Walkley-Black method[11] and total N as described by Dalal *et al*.[12]. Soil inorganic C (carbonate) content was determined by the acid neutralization method[13]. Particle size analysis was made using the pipette method[14] and cation exchange capacity (CEC) as described by Chapman[15].

Results of soil analyses showed that soil samples had a range in organic C and total N, which varied according to the production system. Soils were calcareous and had pH in the alkaline range; they had a range in clay CEC (Table 3).

Among the sites under agricultural production systems, soil samples from those under lowland rice systems (rice double cropping) had higher organic C and total N compared to sites under rice–arable crop sequence or other cropping systems with or without legumes (Table 3).

SOC contents in the soils represent quasi-equilibrium values as the sites have been under the specified systems for 20 or more years. According to recent reports in the literature, sites under agricultural systems attain quasi-equilibrium soil C values between 5 and 30 years depending on the

Table 1. Site characteristics of selected benchmark spots in semi-arid tropical zone of India

Benchmark soil series	District/state	Land-use system (crop rotation)	Mean annual rainfall (mm)	Mean annual temperature (°C)	Soil taxonomy
Jhalipura	Kota/Rajasthan	Agriculture (rice–wheat)	842	27.0	Typic Haplusterts
Jajapur 1	Mehboobnagar/Andhra Pradesh	Agriculture (rice–rice)	792	27.9	Vertic Haplusterts
Teligi	Bellary/Karnataka	Agriculture (rice–rice)	632	26.6	Calcic Haplusterts
Teligi 1	Bellary/Karnataka	Agriculture (rice–rice)	632	26.6	Calcic Haplusterts
Jhalipura	Kota/Rajasthan	Agriculture (soybean–wheat)	842	27.0	Typic Haplusterts
Paral	Akola/Maharashtra	Agriculture (cotton + pigeonpea/sorghum)	794	26.5	Sodic Haplusterts
Konheri	Solapur/Maharashtra	Agriculture (pigeonpea/sunflower–sorghum)	742	26.5	Leptic Haplusterts
Kovilpatti	Tuticorin/Tamil Nadu	Agriculture (cotton + black gram)	660	29.3	Gypsic Haplusterts

Soybean–wheat, Soybean and wheat in sequence or rotation; Cotton + pigeonpea/sorghum, Cotton (rainy season) followed by sorghum intercropped with pigeonpea (post-rainy season).

Table 2. Soil and crop management practices at selected benchmark spots in semi-arid tropical zone of India. Under soil series in parenthesis are given general management status and soil sampling dates

Soil series	Production system	Management level/practice
Jhalipura (FM 2, 11.11.2001)	Irrigated (canal + tube well); paddy–wheat double cropping; 1–2 months fallow; crop–livestock mixed farming system	Improved seeds; 230–260 kg N/ha, 140 kg P_2O_5/ha/yr, no FYM; rice-transplanted
Jajapur 1 (FM, 15.12.2002)	Irrigated (tube well + tank); paddy–paddy double cropping; 2–3 months	Improved seeds; 160–200 kg N/ha, 110–120 kg P_2O_5/ha/yr; stubbles incorporated; rice transplanted
Teligi 1 (LM, 07.01.2002)	Monocropping of rice; lowland rice; 7–8 months fallow	Improved seeds; 150 kg N/ha, 75 kg P_2O_5/ha/yr, 75 kg K_2O/ha/yr, no FYM; stubbles incorporated; rice transplated
Teligi (HM, 07.01.2002)	Monocropping of rice; lowland rice; 7–8 months	Improved seeds; 200–250 kg N/ha, 75 kg P_2O_5/ha/yr, 75 kg K_2O/ha/yr, no FYM; stubbles incorporated; rice transplanted
Jhalipura (FM, 10.11.2001)	Irrigated (canal + tubewell); soybean–wheat double cropping; 2 months fallow	Improved seeds; 150 kg N/ha, 120 kg P_2O_5/ha/yr; FYM 6–8 cartloads/ha/yr
Paral (LM, 19.01.2001)	Rainfed intercropping system of cotton (8 rows) + sorghum (2 rows) + pigeonpea (1 row); 6 months summer fallow; crop–livestock mixed farming system	Improved seeds; 40–60 kg N/ha, 30–40 kg P_2O_5/ha/yr; no FYM
Konheri (FM 09.01.2002)	Dry farming; sorghum (rabi)–pigeonpea–sunflower cropping; 6–8 months fallow	Improved seeds; 45 kg N/ha, 30 kg P_2O_5/ha/yr; stubbles incorporated
Kovilpatti (HM, 15.02.2001)	Rainfed; single crop (or intercrop); winter cropping maize/sorghum–cotton + black gram 2 : 2 ratio; 6 months fallow	Improved seeds; 90 kg N /ha, 10 kg P_2O_5/ha/yr; FYM 12 t/ha + 10 t sheep manure/ha

FM, Farmers' management; LM, Low management; HM, High management.

Table 3. Selected chemical properties in surface (0–30 cm) soil samples of selected benchmark spots in semi-arid tropical regions of India

Series name	pH water	SOC (%)	SIC (%)	TC (%)	Total N (%)	SOC : N	SIC : N	TC : N	Clay CEC
Jhalipura	8.1	0.53	1.10	1.63	0.0443	12 : 1	25 : 1	37 : 1	77
Jajapur 1	8.5	0.88	0.26	1.14	0.082	11 : 1	3 : 1	14 : 1	62
Teligi	8.0	1.03	1.30	2.33	0.062	17 : 1	21 : 1	37 : 1	90
Teligi 1	7.8	0.80	0.96	1.76	0.0551	14 : 1	17 : 1	32 : 1	99
Jhalipura	8.3	0.44	0.45	0.89	0.051	8 : 1	9 : 1	17 : 1	79
Paral	8.2	0.60	1.19	1.79	0.0354	17 : 1	33 : 1	51 : 1	97
Konheri	8.1	0.30	1.08	1.38	0.0241	12 : 1	45 : 1	57 : 1	90
Kovilpatti	8.0	0.40	0.85	1.25	0.0279	14 : 1	30 : 1	45 : 1	92

SOC, Soil organic C; SIC, Soil inorganic C; TC, Total C; CEC, Cation exchange capacity.

soil and native vegetation before opening up the site for agricultural production system[5].

The SOC : N ratio of the soil samples varied from 8 to 17. The widest SOC : N ratio was obtained in Teligi (rice–rice) and Paral (cotton plus pigeonpea/sorghum) systems. Soils under wetland rice (rice–rice system) had a tendency to show wider C : N ratio compared to those under other cropping patterns. The results indicated a change in the quality of organic matter in sites under wetland rice compared to those under arable cropping systems, which had relatively narrow C : N ratios (Table 3). These results are in accordance with those by Olk *et al.*[16], who reported that the C : N ratio of soils increased with the intensity of irrigated rice and the ratio was wider in soils under double- or triple-crop rice than in soils under dryland rice or rice–soybean system.

An attempt has been made to find out the relation between SIC and total N in soils in view of the indirect relation of SIC to form SOC as well as its role in sequestering C in soils of the dry regions[4,17]. The role of SIC in C sequestration and maintenance of soil quality is crucial because calcareous soils cover nearly 229 m ha area of the country[9]. The indirect relation of SIC in the formation of SOC has recently been suggested based on a C transfer model[18].

According to this model, inorganic form of C is converted to organic form by plants through photosynthesis, and in soils through the reaction of carbonate with decomposing organic matter. Furthermore, in the soil SIC gets solubilized through the actions of acidic root exudates and carbonic acid formed by reaction with carbon dioxide from root respiration in aqueous solution. Formation of soluble calcium bicarbonate helps in restoring soluble and exchangeable calcium levels in the soil, which results in the decrease of exchangeable sodium percentage and improvement in soil physical properties. Thus, the cycle of transfer of C from inorganic to organic by plants and from organic to inorganic in the soil provides a better environment for C sequestration and maintaining soil quality[17,18].

It is interesting to note that the SIC : N ratio is relatively narrow in soils under lowland rice double-crop system. A comparative evaluation of TC : N ratios suggests that the narrower values in rice soils indicate a better and healthy pedoenvironment, which keeps the deteriorating effects of $CaCO_3$ formation and concomitant sodicity at bay in these soils[9].

In addition to the effect of submergence (anaerobiosis) or moisture regime, soil characteristics such as texture, especially fine particles, clay minerals and agricultural operations and soil management practices, especially inputs of crop and organic residues also affect the acquisition of organic matter by soil and its organic matter status[6].

For example, in a long-term experiment on a Vertisol (clay in texture) cropping system with improved soil and nutrient management along with the implementation of soil and water conservation practices increased crop productivity and C sequestration in the soil[10]. Similar results were obtained when black soil in aridic bio-climatic system (Typic Haplusterts) was brought under improved management practices; greater amounts of C were sequestered in the soil under improved than under traditional cropping management system[19].

Balance between organic matter inputs and decomposition is the primary determinant of organic matter accumulation or depletion in soils[6]. It would seem that under the prolonged paddy rice (submerged conditions) environment, there is net addition of organic matter in the soil, while the balance is generally negative under arable cropping systems.

The results support the conclusion that soils under lowland rice system preferentially accumulate organic matter and are important for sequestering atmospheric C. Soil submergence, as practised in lowland rice systems, also seems to prevent formation of $CaCO_3$ and thus prevents or slows down degradation of calcareous soils such as Vertisols to sodic soils. In addition to organic matter, the ameliorative effects of flooding on pedoenvironment and fertility are influenced by chemical and electrochemical properties of soils[8,20,21].

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Water quality variations as linked to landuse pattern: A case study in Chalakudy river basin, Kerala

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Linkage between landuse pattern and water quality is an emerging field of multidisciplinary research. Change in landuse practices, particularly urbanization and intensive agriculture lead to water quality deterioration. The present study in Chalakudy river basin in Kerala based on an analysis of 27 water samples spread over five landuse types and monitored during four seasons, substantiated this argument. Samples under urban landuse showed poor water quality throughout the year. Correlation analysis of various parameters indicated seasonality in physico-chemical characteristics of river water, which was linked to fluctuations of drainage discharge and changes in landuse pattern.

Keywords: Chalakudy river basin, landuse pattern, physico-chemical characteristics, water quality.

SPATIAL variation in river water quality has been reported in various catchment studies and most of the researches focused on hydrological pathways and biogeochemistry linked to vegetative canopy cover, soil and rock types and discharge[1]. Problems arising out of water quality deterioration are as severe as those related to water availability. It is reported that about 70% of India's surface water resources is already contaminated[2]. The condition in Kerala is equally alarming and water in various stretches of many rivers in the state is not potable[3].

Apart from climate-induced changes which are long-term and therefore slow, direct anthropogenic modification of landcover such as agriculture, aforestation, mining, urbanization, industrialization, and intervention on hydrological regimes like irrigation and damming have resulted in marked changes in water quality[4]. Several studies were attempted to address the linkage among landuse practices, water quality, sediment geochemistry, nutrient loading and drainage discharge[5–7]. However micro-level studies covering landuse change, water quality and its seasonal variation are few[8]. The present study in Chalakudy river basin is one such attempt to assess water quality in different seasons and link the spatial and seasonal variations of water quality to landuse variations. This is important, especially when investigating diffused non point source pollution[8].

The Chalakudy river basin with an area of 1525 km^2, is a tributary of the Periyar, the largest river in Kerala. There are six reservoirs impounded in this basin. The present study is limited to the stretch from the Poringalkuttu reservoir to the confluence of the Chalakudy river with the Periyar (Figure 1). The length of this stretch is 80 km, with a catchment area of 583 km^2. Relief varies from 20 m at the river mouth to 1000 m in the northeastern part of the catchment. Dominant rock types are charnockite and biotite gneiss, with recent sediments in the western part and along the river. Geomorphologically, this stretch is characterized by floodplain, transitional plain, low rolling terrain, moderately undulating terrain, highly undulating terrain and hilly area. Average annual rainfall in this area is around 3300 mm, varying from a little over 3000 mm in Chalakudy town to 3700 mm in Poringalkuttu. Seasonal variation of temperature is within 5°C. Total average annual drainage discharge (1980–2000) is 1421.81 million m^3 near Chalakudy town, as reported by the Irrigation Department, Government of Kerala.

Current landuse data (2002) were extracted by scanning IRS-1D PAN (P 099-R 066, 58 B/7 SE and SW dt. 12 January 2002) and IRS-1D L3 (P 099-R 066, 58 B/7 dt. 12 January 2002, FCC-merged) images supplemented by extensive field investigation. Topographical maps (1 : 50,000 scale) provided information about past landuse (1966–67). Table 1 presents landuse pattern during these two time periods and the changing trend. Forest and forest plantations, and settlement with mixed tree crops dominate landuse in this basin. This area also experiences widespread landuse changes. Paddy fields have reduced considerably. The area under agglomerated settlement has recorded the highest growth of +75%, which is the emerging trend in the state.

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