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Establishment of critical limits of indicators and indices of soil quality in rice-rice cropping systems under different soil orders

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ABSTRACT

Rice-rice is one of the major cropping systems in Indo-Gangetic Plains (IGP) of South Asia. Assessment of soil quality and identification of key indicators with their critical limits are very much important for maintaining normal functioning of the soil and productivity of crops, particularly of wet land rice. The present investigation was undertaken to identify sensitive soil quality indicators and to develop soil quality indices and establishment of their critical limits in Inceptisols, Entisols and Alfisols collected from farmers' fields with long-term rice-rice cropping system in sub-tropical India. The soil samples were analysed for 37 physical, chemical and biological properties. Principal component analysis (PCA) was performed to create minimum data set (MDS) of physical, chemical and biological indicators which were encompassed to develop unified soil quality index (SQI) under different soil orders. The SQI thus developed was highest in Inceptisols (0.66 to 0.89) followed by Entisols (0.23 to 0.76) and Alfisols (0.37 to 0.60). The upper and lower critical limits for key indicators as well as SQI were determined using scattered plot technique involving relative yields of rice (RY) and different soil quality indicators as well as SQI. The critical limit equivalent to 80% and 40% of relative yield were treated as upper and lower critical limits of selected key indicators and SQI. The adequacy classes for each of selected key indicator as a function of relative yield of rice were established based on the following criteria: <40% low, 40–80% moderate and >80% adequate. The upper and lower critical limits of the indicators selected under rice-rice cropping systems in Inceptisols were available Zn (1.7 and 1.2 mg kg^{-1}), bulk density (1.2 and 1.6 Mg m^{-3}), β-glucosidase activity (68 and 18 μg p-nitrophenol g^{-1} soil h^{-1}) and urease activity (64 and 24 μg NH_4 g^{-1} soil 2 h^{-1}), in Entisols were dehydrogenase activity (93 and 12 μg TPF g^{-1} soil 24 h^{-1}), aggregate stability (66 and 11%), total organic C (11.6 and 10.7 g kg^{-1}) and pHw (5.7 and 5.3) and in Alfisols were oxidisable organic C (7.8 and 5.0 g kg^{-1}), β-glucosidase activity (51 and 15 μg p-nitrophenol g^{-1} soil h^{-1}), aggregate stability (52 and 19%) and mineralizable C (273 and 173 μg C g^{-1} soil), respectively. The upper and lower critical limits established for key soil quality indicators as well for Inceptisols (0.85 and 0.56), Entisols (0.23 and 0.65) and Alfisols (0.37 and 0.56) could periodically be judged for maintaining/enhancing soil quality and yield sustainability through the employment of optimum management practices in rice-rice cropping systems of subtropical India.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple food crops for more than half of the world's population and influences the livelihoods and economies of several billion people (IRRI, 2006). The Indo Gangetic Plain of South Asia is the major rice producing region which occupies 60 million ha of land under rice cultivation and produces >225 million tons of rice, accounting for 37.5% of global area and 32% of global production (Mohanty, 2014). However, the productivity of the rice-rice cropping system is low and it continues to decline because of continuous submergence that changes the soil environment especially destruction of soil structure, increased bulk density and reduced hydraulic conductivity (Ghoshal, 2004) and subsequent deterioration of soil quality probably be due to limited organic recycling and imbalanced use of fertilizers (Shahid et al., 2013). Therefore, this system should have different sets of key indicators and their critical limits for maintaining normal functioning of soil and productivity of rice. The soil quality is defined as the capacity of specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitat (Karlen et al., 1997). Though the direct assessment of soil quality is difficult, it may be inferred from management-induced

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Table 1
Study area and experimental details.

Parameters	Soil order		
	Inceptisols (n = 20)	Entisols (n = 20)	Alfisols (n = 20)
Climate	Subtropical humid	Subtropical humid	Subtropical humid
Soil	Clay	Sandy clay	Sandy clay loam
Agroecosystem	Irrigated	Irrigated	Irrigated
Cropping system	Rice-rice	Rice-rice	Rice-rice
Tillage	Tractor, puddling	Tractor, puddling	Country plough, puddling
Inorganic input (N:P:K kg ha^{-1}) (average of the sites)	Wet season rice-60:50:40	Wet season rice-50:40:40	Wet season rice-50:40:40
	Dry season rice-110:100:80	Dry season rice-80:100:60	Dry season rice-60:50:40
Organic input (used by about 40% of farmers) (t ha^{-1})	Wet season rice-2	Wet season rice-3	Wet season rice-2.5
	Dry season rice-5	Dry season rice-2	Dry season rice-3
Annual rice yield (t ha^{-1})	9.3	8.3	7.2

Table 2
Physical attributes of soils under different soil orders.

Soil properties	Unit	Soil order		
		Inceptisols (n = 20)	Entisols (n = 20)	Alfisols (n = 20)
Clay	(g kg^{-1})	492.7 ± 9.7a	389.5 ± 20.9b	314.4 ± 15.9c
Bulk density	(Mg m^{-3})	1.25 ± 0.03b	1.23 ± 0.02a	1.47 ± 0.02a
Saturated hydraulic conductivity	(cm h^{-1})	0.19 ± 0.01c	0.30 ± 0.01b	0.85 ± 0.03c
Total water stable aggregates	(%)	66.0 ± 2.8a	60.8 ± 3.1a	44.5 ± 1.8b
Aggregate stability	(%)	59.3 ± 2.43a	54.1 ± 4.87a	38.1 ± 2.64b
Aggregate ratio		1.85 ± 0.28a	1.36 ± 0.21a	0.67 ± 0.05b
Mean weight diameter	(mm)	1.53 ± 0.06a	1.41 ± 0.05a	1.12 ± 0.09b
Geometric mean diameter	(mm)	1.15 ± 0.03a	1.07 ± 0.04a	0.81 ± 0.04b

Values (mean ± standard error) in each row (between the soils) for particular soil parameter followed by different lower case letters are significant according to Duncan's Multiple Range Test at $P = 0.05$.

changes in soil properties (Mandal et al., 2005; Shahid et al., 2013; Takoutsing et al., 2016). Andrews and Carroll (2001) described a statistical method for assessing the soil quality index. When the influence of factors not directly related to soil quality is minimized, crop yield can be considered a field indicator for evaluating sustainability that takes the satisfaction of the farmer into account (Gomez et al., 1996). There is an urgent need to adopt appropriate soil and crop management practices in this ecosystem, which can reduce soil degradation or maintain soil quality at desired level. Selection of key indicators and their critical limits are extremely important for assessing the management induced changes in soil quality (Arshad and Martin, 2002). However, the establishment of critical limits of indicators is difficult and the critical limits of available soil nutrients were calibrated (Tisdale et al., 1993). The critical limit is defined as the nutrient concentration that is necessary to reach either 80% or 90% of the maximum economic yield (Cantarutti et al., 2007). The specific crop yield condition (ranging from low to high) could be useful in developing a guideline for interpretation of individual key soil indicator (Lopes et al., 2013). The key indicators were interpreted as a function of relative yield of rice. Most of the studies on soil quality have been carried out on experimental sites with controlled treatments and conditions throughout the world (Lima et al., 2008; Li et al., 2013; Liu et al., 2014) including India (Bhaduri and Purakayastha, 2014; Masto et al., 2007; Manna et al., 2005; Chaudhury et al., 2005; Mandal et al., 2008). But very few studies have been carried out on soil quality in the farmers' field conditions under various soil types in India. India has a variety of soils and among these Inceptisols, Entisols and Alfisols are the dominant soil orders (Sarkar et al., 2001). Our hypothesis was that the excessive tillage, imbalanced fertilization,

Table 3
Chemical attributes of soils under different soil orders.

Soil properties	Unit	Soil order		
		Inceptisols (n = 20)	Entisols (n = 20)	Alfisols (n = 20)
pHw		6.2 ± 0.04a	5.6 ± 0.1b	5.4 ± 0.1c
pH_{Ca}		5.4 ± 0.08a	4.7 ± 0.1b	4.6 ± 0.1b
Very labile C	(g kg^{-1})	4.9 ± 0.1a	4.8 ± 0.1a	2.9 ± 0.1b
Oxidisable organic C	(g kg^{-1})	9.2 ± 0.1a	8.8 ± 0.1a	6.3 ± 0.2b
Total organic C	(g kg^{-1})	11.9 ± 0.2a	11.5 ± 0.1a	8.2 ± 0.3b
Total Nitrogen	(g kg^{-1})	0.87 ± 0.01a	0.83 ± 0.02a	0.70 ± 0.02b
Cation exchange capacity		(c mol (p+) kg^{-1})	21.7 ± 1.2a	17.0 ± 1.4b
11.8 ± 1c				
Available N	(kg ha^{-1})	190.4 ± 8.2a	185.6 ± 9.7a	177.7 ± 5.5b
Available P	(kg ha^{-1})	24.8 ± 1.8a	20.7 ± 1.5a	19.2 ± 2.6a
Available K	(kg ha^{-1})	163.6 ± 7.1b	220.5 ± 22.7a	92.6 ± 8.3c
Exchangeable Ca		(c mol (p+) kg^{-1})	12.7 ± 0.6a	7.5 ± 0.6b
5.6 ± 0.6b				
Exchangeable Mg		(c mol (p+) kg^{-1})	7.8 ± 0.5a	4.4 ± 0.4b
3.6 ± 0.4b				
Available Zn	(mg kg^{-1})	1.55 ± 0.04a	1.34 ± 0.05b	1.31 ± 0.08b
Available B	(mg kg^{-1})	0.78 ± 0.03b	1.10 ± 0.1a	0.56 ± 0.04c

Values (mean ± standard error) in each row (between the soils) for particular soil parameter followed by different lower case letters are significant according to Duncan's Multiple Range Test at $P = 0.05$.