International Journal of Soil Science 1 (3): 196-206, 2006
ISSN 1816-4978

Indices to Assess Quality, Productivity and Sustainable Health of Soils Receiving Low Cost Biological and/or Conventional Inputs

[1]B. Hameeda, [2]O.P. Rupela, [2]S.P. Wani and [1]Gopal Reddy
[1]Department of Microbiology, Osmania University, Hyderabad-500 007, AP, India
[2]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, AP, India

Abstract: Soil quality was assessed from four different treatment plots T1, T2, T3 and T4 of a long-term field experiment at ICRISAT, Patancheru. The four different crop-husbandry systems were: T1 = low-cost system 1, T2 = low-cost system 2, T3 = conventional system and T4 = same as T3+biomass as in T2. The parameters used in the study were nutrient, biological, microbial and crop yield. Treatment plots T1 and T2 showed substantially more nitrogen (15-29%) and phosphorus (17-23%), than that was added to T3, largely as chemical fertilizers. Biomass C and N of treatment plots T1 and T2 was also 22-35% more than T3. The overall results on microbial populations suggested that soil from plots T1 and T2 were more active than that of T3. Application of low-cost biological inputs improved soil health and increased yields of T1 and T2, which was at par or better than T3 and T4 plots, where chemicals were applied. A new approach was used to calculate sustainability index based on the area of a polygon, where the four vertices are represented by nutrient, biological, microbial and crop indices. The sustainability index of treatment plot T2 that received low cost biological inputs was highest (2.29) followed by T4 (2.10), T1 (2.07) and the least was with T3 (1.56).

Key words: Cropping systems, soil microorganisms, soil productivity, soil quality, sustainability index

Introduction

Crop production systems that require chemical fertilizers, pesticides, machinery for tillage and irrigation water are becoming expensive. Inappropriate use of these has contributed to loss of biodiversity, eutrophication of surface water, contamination of ground water and loss of organic matter (OECD, 1999). Crop residues are an important potential source of soil organic matter (which is very low in tropics). Still large quantities of crop residues are burnt (worth US $ 15 million annually in Punjab, India, alone (Sidhu *et al*., 1998) resulting in loss of N and creating environmental pollution. Biological approaches such as the use of biomass (crop residues), organic manures (Pare *et al*., 2000; Delate and Camardella, 2004; Biederbeck *et al*., 2005) and microbial inoculants as biofertilizers and/or antagonists of phytopathogens (Vessey, 2003; Correa *et al*., 2004) are being considered among the diverse technological practices of low-input agricultural systems for decomposition and mineralization of organic matter and release of nutrients for enhancing plant growth. Application of low-cost biological inputs can be made more efficient by applying the scientific knowledge to improve soil health and crop productivity. Soil health/quality is the focus of on-going conservation and degradation processes, depending highly on nutrient, biological and microbiological

Corresponding Author: Gopal Reddy, Department of Microbiology, Osmania University, Hyderabad-500 007, AP, India Tel:+91-40-27682246 Fax: +91-40-27090661

components of soil and influences crop yield (Parr *et al*., 1992; Halvorson *et al*., 1996). These various approaches can be combined into an integrated soil-plant-animal cropping system for attaining sustainability.

Several indices have been proposed to assess soil quality using soil microbial population and enzyme activities (Nannipieri *et al*., 1990) and microbial indices using fatty acid methyl ester and terminal restriction fragment length polymorphism (Suzuki *et al*., 2005). Kang *et al*. (2005) used a new triangular approach when there were three factors (nutrient, microbial and crop index) to assess soil quality and sustainability in wheat-based cropping systems. In calculating the index, each parameter value was divided by the respective threshold value (arithmetic mean value of treatments for a parameter) as given below:

$$Iij = \frac{Aij}{Thj}$$

where Iij is the index value for ith treatment corresponding to Jth parameter in an experiment, Aij is the actual measured value for the ith treatment and jth parameter in an experiment and Thj is the threshold value for jth parameter. In this method microbial indices included both the biological and microbial parameters. But microbial populations possess the ability to function as excellent indicators of change in soil health (Pankhurst *et al*., 1995). Therefore, in the present study, a polygonal approach was used to evaluate the sustainability of different cropping systems using biological, microbial, nutrient and crop index. The emphasis was to separate the biological and microbial parameters.

Materials and Methods

Design of Field Experiment

The experiment was initiated in 1999 at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India to determine the potential of harvesting high yields from crops that receive low-cost biological inputs for plant growth and pest management. Experiment was conducted at field BW3, where the soil type is deep Vertisol, pH 8-8.2 and electrical conductivity, 0.16 to 0.22 dS m^{-1}. The area is fully rainfed, with annual mean rainfall at Patancheru of 783 mm, which allows two crops to be grown in a year either as intercrops or sequential crops. The experiment had larger plots of 0.2 ha for each treatment, with a total area of 1.02 ha including non-cropped areas. Details of each treatment comprising of year of start, treatments and cropping sequence are presented in Table 1.

Soil Sampling

Field experiment had four treatment plots T1, T2, T3 and T4. After a five-year experimental cycle, close to the period of harvesting stage, soil sampling was done during fifth and sixth year from the four treatment plots T1, T2, T3 and T4. Sampling was done from 0-10 and 10-20 cm depth with a 40 mm diameter soil core. Soils from each depth were collected, pooled, mixed well and used for analysis. Samples were pooled to five replications from each treatment. The samples were air dried and passed through 2 mm sieve to prepare these for chemical and biological properties. However, for microbiological properties the soil samples were preserved in cold room (4°C) till they were processed. Soil quality was assessed based on the below given parameters and analysis were done using soils from all the four treatment plots at the end of fifth and sixth years (2004 and 2005).

Biological Indicators

Biological indicators were studied as per standard methods, which included soil respiration by CO_2-C evolution method (Anderson and Domsch, 1978), Microbial biomass C and N, chloroform-fumigation and incubation (Jenkinson, 1988), phosphatase (Eivazi and Tabatabai, 1977), dehydrogenase activity (Casida *et al*., 1964).

Table 1: Four different crop husbandry systems in continuing long-term experiment (Rupela *et al*., 2005) of BW3 (Vertisol) field[1] at ICRISAT, Patancheru

	Treatment plots			
Act/Inputs	T1	T2	T3	T4
Tillage	Zero-till	Zero-till	Conventional (bullock plough)	Conventional (bullock plough)
Sowing	Sd drill	Sd drill	Sd drill	Sd drill
Microbial inoculants*	+	+	-	-
Biomass ($t\ ha^{-1}\ yr^{-1}$ first 3 years only)	10 Rice straw as surface mulch	10 Farm-waste, stubble and hedgerow foliage as surface mulch	None	10 Farm waste, stubble and hedgerow foliage incorporated
Compost ($t\ ha^{-1}$)	1.5-1.7 annual	1.5-1.7 annual	1.8 (1 in 2 year)	1.8 (1 in 2 year)
Fertilizer (N) Urea ($kg\ N\ ha^{-1}$)	0	0	80	80
Fertilizer (P) $kg\ P\ ha^{-1}$ (1 in 2 year)	20 (RP)	20 (RP)	20 (SSP)	20 (SSP)
Pest management	Biopesticides[a]	Biopesticides	Chemical pesticides	Chemical pesticides
Weeding	Manual, weeds retained	Manual, weeds retained	Manual, weeds discarded	Manual, weeds discarded

[1]Same crops were grown in all treatments each year: Year 1 pigeonpea-chickpea sequential (June 1999-May 2000); Year 2 sorghum/pigeonpea intercrop (June 2000-May 2001); Year 3 cowpea/cotton intercrop (June 2001-May 2002); Year 4 maize/pigeonpea intercrop (June 2002-May 2003); Year 5 cowpea/cotton intercrop (June 2003-May 2004); Year 6 maize/pigeonpea intercrop (June 2004-May 2005), T1 = Low-cost system 1, No tillage, Rice straw as surface mulch+Biological inputs for plant growth and pest management. T2 = Low-cost system 2, No tillage, farm waste as surface mulch+Biological inputs for plant growth and pest management. T3 = Conventional system, tillage, integrated nutrient management and chemicals for plant growth and pest management. T4 = Same as T3+Farm waste as biomass as in T2. *Microbial inoculants applied were *Bacillus circulans* EB 35, *Serratia marcescens* EB 67 and *Pseudomonas* sp. CDB 35 (Hameeda *et al*., 2006) along with other inoculants like *Rhizobium* and *Azotobacter*. [a]Biopesticide formulation (microorganisms, herbal extracts and vermiwash) developed at ICRISAT

Microbial Indicators

Microbiological indicators included the characterization of bacteria, fungi, actinomycetes, plant growth promoting and antagonistic bacteria. Ten gram of soil sample from the four different treatment plots T1, T2, T3 and T4 was added to 90 mL water. Appropriate dilutions were plated on different media. LB agar for bacteria, PDA+streptomycin (500 mg L^{-1}) for fungi, actinomycetes isolation agar for actinomycetes, *Pseudomonas* Isolation Agar (PIA) for fluorescent pseudomonads, P solubilizers on RP buffered medium (Gyaneshwar *et al*., 1998), Chromeazurol S (CAS) agar for siderophore producers (Schwynn and Neilands, 1987), organic P mineralizers (phytase positive) using phytic acid as sole P source (Richardson and Hadobas, 1997). Antagonistic microorganisms against *Macrophomina phaseolina* were enumerated on PDA by the two-layer method (Rupela *et al*., 2003). All the plates were incubated at 30±1°C. Plates were observed everyday up to four days and the number of colonies were expressed as log colony forming units (CFU) g^{-1} dry weight of soil.

Chemical Indicators

Soil nutrient status was studied by estimating total N (modified Kjeldahl digestion method, Dalal *et al*., 1984), total P, available P and K by following standard methods (Okalebo *et al*., 1993), organic carbon (OC)% (TOC analyzer, Primacs).

Crop (Productivity) Indicators

Crop productivity was determined based on the grain yield and stover of cotton and cowpea at fifth year (2003-04) and maize and pigeonpea, at sixth year (2004-05).

Derivation of Sustainability Indices

The choice of measurable parameters that were studied to define the sustainability indices of soil were biological, microbiological, nutrient and crop indicators as mentioned above. Means of two-year data of 0-20 cm depth of the four different treatment plots (T1, T2, T3 and T4) of BW3 field were used to derive the sustainability index.

Biological index (BI_i) was calculated as an average of index values (I_{ij}) of the six soil properties (acid phosphatase, alkaline phosphatase, dehydrogenase, soil respiration, microbial biomass C and N) studied in the four treatments plots (T1, T2, T3 and T4) of field experiment

$$BI_i = \frac{1}{6_j} \sum_{j=1}^{6} I_{ij}$$

Microbial index (MI_i) was calculated as an average of index values (I_{ij}) of the eight microbial (bacteria, fungi, actinomycetes, pseudomonads, phosphate solubilizing bacteria (PSB), phytase and siderophore producers and antagonistic) populations studied in the four treatment plots (T1, T2, T3 and T4) of field experiment

$$MIi = \frac{1}{8_j} \sum_{j=1}^{8} I_{ij}$$

Nutrient index (BI_i) was calculated as an average of index values (I_{ij}) of the five parameters (total N and P, available P and K, OC) studied in the four treatment plots (T1, T2, T3 and T4) of field experiment.

$$NI_i = \frac{1}{5_j} \sum_{j=1}^{5} I_{ij}$$

Crop Index (CIi) was calculated as an average of index values (I_{ij}) of crop yield and stover dry weight at fifth (cotton/cowpea) and sixth year (maize/pigeonpea) in the four treatment plots (T1, T2, T3 and T4) of field experiment.

$$CI_i = \frac{1}{4_j} \sum_{j=1}^{4} I_{ij}$$

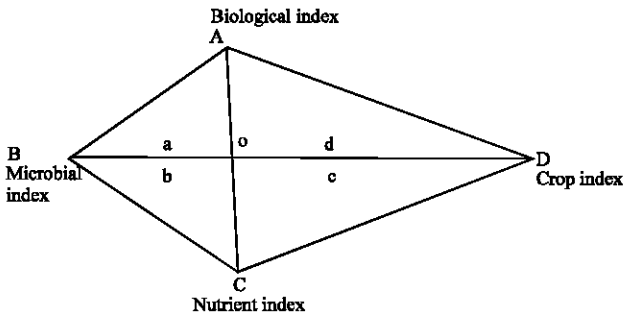

Fig. 1: Measurement of sustainability of cropping system from the polygon area

Sustainability index of the soil was measured as the area of polygon with biological index, microbial index, nutrient index and crop index of soil at four vertices; they were represented in radar graph as a, b, c and d, respectively, which are the four lines of different lengths originating from a common point 'O'. By joining the tail ends of these four lines, polygon is formed as shown in Fig. 1. The sustainability index of the system is given as:

Sustainability of system = Area of polygon ABCD

= Area (Δ AOB+Δ BOC+Δ COD+Δ DOA)

= 1/2 ab sin 90+1/2 bc sin 90+1/2 cd sin 90+1/2 da sin 90

= 1/2 sin 90 (ab+bc+cd+da)

= 1/2 * 1 (ab+bc+cd+da) .....(i)

In order to have a sustainable system, the absolute value of each parameter should be equal or greater than the threshold value and the sustainability index should be always positive and greater than 2.00; the higher the value, the more sustainable the system. The least value of sustainability index (2.00) is calculated from Eq. (i), by putting the corresponding indices of biological activity (a) microbial activity (b), nutrient status (c) and crop index (d) equal to 1.

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using Genstat 6.1 statistical package (Lawes Agricultural Trust, Rothamsted, UK). Mean values in each treatment were compared using least significant differences at 5% probability ($p = 0.05$).

Results

Characterization of Biological Indicators of Soil-quality

Of the different parameters measured to assess the biological activity in soil samples from four different crop husbandry systems, more activity was noted in plots T2, T4 and T1 compared to T3. Soil respiration was more by 23-47% than in T3 (which had a rate of 100 mg C kg^{-1} soil per 10 days); microbial biomass C and N was 22-35% higher when compared to T3. In soil enzyme activities, increase in phosphatase activity was 8-27% (over 289 units for acid and 860 units for alkaline phosphatase in T3) (Table 2).

Characterization of Microbial Indicators of Soil-quality

The overall results on microbial populations strongly suggested that soil from plots T1 and T2 were more active than that of T3. Population ($\log_{10}$ g^{-1} soil) of bacteria was 5.4-5.7, fungi 3.1-3.4 in the four treatment plots (Table 3). Actinomycetes population was 9 times higher in T1 ($\log_{10}$ 4.7) when compared to T3 ($\log_{10}$ 3.8). Similarly, population of plant growth promoting bacteria such as *Pseudomonas*, siderophore producers, P solubilizers and phytase producers were 8-17 times more in T2 when compared to T3. However, the population of antagonistic bacteria was 5-6 times more in T1, T2 and T4 when compared to T3 (Table 3).

Characterization of Nutrient Indicators of Soil-quality

In the different crop husbandry systems, there was an increase in 15-29% total N and 17-23% total P, 25-33% available K and 6-23% available P in T1 and T2, relatively more than in T3. However the organic carbon (OC) content did not vary significantly among the four treatment plots (Table 4).

Characterization of Crop Yield as Productive Indicators of Soil-quality

It was important to note that both T1 and T2, produced similar yields of crops that were grown during the fifth and sixth year when compared to T3 that received chemical fertilizers. Stover yield of both the crops was marginally higher in T4 when compared to the other three plots T1, T2 and T3 (Table 5).

Table 2: Biological indicators of soil from four crop husbandry systems of a long-term field experiment (2003-05)

	Treatment plots					
Properties	T1	T2	T3	T4	LSD (p = 0.05)	CV (%)
Soil respiration (mg C kg^{-1}, 10 day^{-1})	123 (±11.5)	137 (±10.5)	100 (±5.5)	147 (±3.5)	17.3	4.3
Microbial biomass C (mg C kg^{-1}, 10 day^{-1})	529 (±5.0)	524 (±1.5)	404 (±2.0)	492 (±14.0)	38.5	2.5
Mineral N mg N kg^{-1}	11 (±1.0)	11 (±0.0)	9 (±0.0)	14 (±1.0)	2.6	7
Net N mineralization mg N kg^{-1}	1.8 (±0.1)	-0.30 (±0.3)	1.7 (±1.01)	1.02 (±0.8)	1.9	89
Microbial biomass N (mg C kg^{-1}, 10 day^{-1})	34 (±1.0)	36 (±1.5)	26 (±0.5)	32 (±1.0)	4.9	5
Acid phosphatase (µg p-NP g^{-1} h^{-1})[a]	309 (±1.0)	362 (±30.1)	289 (±5.5)	333 (±24.1)	100.9	10
Alkaline phosphatase (µg p-NP g^{-1} h^{-1})[a]	947 (±10.0)	1031 (±22.6)	860 (±30.6)	1024 (±13.0)	105.5	3.4
Dehydrogenase (µg TPF g^{-1} 24 h^{-1})[b]	139 (±5.5)	137 (±0.0)	125 (±5.0)	138 (±4.0)	21.5	5

[a] p-NP- para nitro phenol; [b]TPF- Triphenylformazan, T1 = Low-cost system 1, No tillage, rice straw as surface mulch+Biological inputs for plant growth and pest management. T2 = Low-cost system 2, No tillage, farm waste as surface mulch+Biological inputs for plant growth and pest management. T3 = Conventional system, tillage, integrated nutrient management and chemicals for plant growth and pest management. T4 = Same as T3+Farm waste as biomass as in T2

Table 3: Microbiological indicators (population $\log_{10} gm^{-1}$ dry soil) of soil from four crop husbandry systems of a long-term field experiment (2003-05)

	Treatment plots					
Functional groups*	T1	T2	T3	T4	LSD (p = 0.05)	CV (%)
Bacteria	5.6 (±0.05)	5.7 (±0.02)	5.4 (±0.05)	5.7 (±0.04)	0.21	1.2
Fungi	3.2 (±0.05)	3.4 (±0.10)	3.1 (±0.10)	3.1 ±0.10)	0.33	3.3
Actinomycetes	4.7 (±0.05)	4.4 (±0.0)	3.8 (±0.30)	4.2 (±0.15)	0.59	4
Pseudomonas	4.1 (±0.15)	4.1 (±0.50)	3.3 (±0.10)	3.3 (±0.05)	1.04	9
Siderophore	3.6 (±0.10)	4.2 (±0.35)	2.9 (±0.50)	3.7 (±0.60)	0.98	9
PSB	1.4 (±0.05)	2.3 (±0.55)	0.6 (±0.6)	1.2 (±0.75)	2.66	62
Phytase producers	3.8 (±0.55)	4.3 (±0.10)	3.2 (±0.40)	3.9 (±0.10)	1.01	8
Antagonistic bacteria	4.0 (±0.00)	3.9 (±0.10)	3.4 (±0.40)	4.0 (±0.25)	1.25	10

*plant growth promoting and antagonistic bacteria, PSB = phosphate solubilizing bacteria, T1 = Low-cost system 1, No tillage, rice straw as surface mulch+Biological inputs for plant growth and pest management. T2 = Low-cost system 2, No tillage, farm waste as surface mulch+Biological inputs for plant growth and pest management. T3 = Conventional system, tillage, integrated nutrient management and chemicals for plant growth and pest management. T4 = Same as T3+Farm waste as biomass as in T2

Table 4: Chemical (nutrient) indicators of soil from four crop husbandry systems of a long-term field experiment (2003-05)

	Treatment plots					
Chemical properties	T1	T2	T3	T4	LSD (p = 0.05)	CV (%)
Total N (ppm)	754 (±16.5)	842(±43.6)	653 (±68.2)	605 (±37.1)	202	9
Total P (ppm)	344 (±11.5)	363 (±53.7)	297 (±50.1)	286 (±54.2)	92.6	9
Available K (ppm)	220 (±3.5)	234 (±9.5)	175 (±5.0)	192 (±3.0)	23.3	4
Available P (ppm)	2.1 (±0.55)	1.8 (±0.59)	1.4 (±0.18)	1.9 (±0.10)	1.66	29
OC (kg C ha^{-1})	12 (±1.0)	12.5 (±2.5)	10 (±2.0)	12 (±1.0)	3.4	9

T1 = Low-cost system 1, no tillage, rice straw as surface mulch+Biological inputs for plant growth and pest management. T2 = Low-cost system 2, no tillage, farm waste as surface mulch+Biological inputs for plant growth and pest management. T3 = Conventional system, tillage, Integrated nutrient management and chemicals for plant growth and pest management. T4 = Same as T3+Farm waste as biomass as in T2

Table 5: Productive indicators (crop yield and stover dry weight) in the four different crop husbandry systems of a long-term field experiment (2004-2005)

	Treatment plots					
Stover/yield (t ha^{-1})	T1	T2	T3	T4	LSD (p = 0.05)	CV (%)
Cotton and maize yield	3.2 (±1.91)	3.1 (±1.83)	3.3 (±1.93)	3.8 (±2.22)	0.77	7
Cotton and maize stover	7.5 (±3.73)	7.3 (±3.30)	7.7 (±3.4)	8.7 (±4.3)	2.16	9
Legume yield	0.7 (±0.24)	0.7 (±0.21)	0.6 (±0.27)	0.6 (±0.25)	0.13	6
Legume stover	2.0 (±0.37)	2.2 (±0.56)	2.0 (±0.08)	2.5 (±0.49)	0.94	13

T1 = Low-cost system 1, No tillage, rice straw as surface mulch+Biological inputs for plant growth and pest management. T2 = Low-cost system 2, No tillage, farm waste as surface mulch+Biological inputs for plant growth and pest management. T3 = Conventional system, tillage, integrated nutrient management and chemicals for plant growth and pest management. T4 = Same as T3+Farm waste as biomass as in T2

Table 6: Sustainability indicators of soil quality from four different crop husbandry systems (T1 to T4)

Treatment plots	Biological index	Microbiological index	Nutrient index	Crop index	Sustainability index	System
T1	1.01	1.02	1.07	0.98	2.07	Sustainable
T2	1.07	1.09	1.11	1.00	2.29	Sustainable
T3	0.85	0.85	0.86	0.97	1.56	Unsustainable
T4	1.08	0.98	0.95	1.09	2.10	Sustainable

T1 = Low-cost system 1, No tillage, rice straw as surface mulch+Biological inputs for plant growth and pest management. T2 = Low-cost system 2, No tillage, farm waste as surface mulch+Biological inputs for plant growth and pest management. T3 = Conventional system, tillage, integrated nutrient management and chemicals for plant growth and pest management. T4 = Same as T3+Farm waste as biomass as in T2

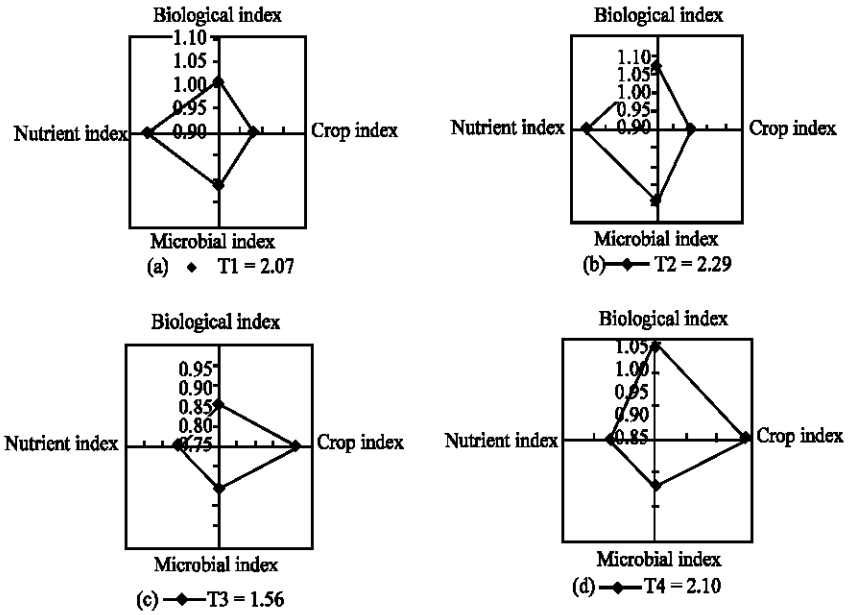

Fig. 2: Sustainability indices of soil quality from four treatments plots (a) T1, (b) T2, (c) T3 and (d) T4 of a long-term field experiment, (a)T1 = Low-cost system 1, no tillage, rice straw as surface mulch+Biological inputs for plant growth and pest management, (b)T2 = Low-cost system 2, no tillage, farm waste as surface mulch+Biological inputs for plant growth and pest management, (c) T3 = Conventional system, tillage, integrated nutrient management and chemicals for plant growth and pest management, (d) T4 = Same as T3+Farm waste as biomass as in T2

Characterization of Sustainable Indicators to Assess Soil-quality

In the four different crop husbandry systems, treatment plot T2, that received farm waste and microbial inoculants was the most sustainable (sustainable index of 2.29, Table 6 and Fig. 2). The lack of sustainability of the treatment plot T3 was due to low microbiological (0.85), biological (0.85) and nutrient (0.86) indices that gave a sustainable index of 1.56 (Fig. 2). In treatment plots T1 (index 2.07) and T4 (index 2.10), the biological, microbiological and nutrient indices were >1.00, thus making the two crop husbandry systems sustainable (Table 6 and Fig. 2).

Discussion

Characterization of Indicators of Soil Quality

Soils with more biomass, a source and sink for nutrients will be able to release nutrients more rapidly. When microbial biomass is increased the availability of N and P is also increased that is reflected with improved soil quality and productivity. Increased biomass C and N which resulted in improved production and carbon sequestration was reported by Wani *et al*. (2003) in legume based cropping of an improved system that received integrated nutrient management application (El-Swaify *et al*., 1985). In present studies, biomass C and N of plots T2 and T4 was significantly higher than T3 (Table 2). With an increase in biomass C (23-32%), there was an increase in mineral N (22-55%), microbial biomass N (22-35%) and total N (15-29%) in the treatment plots T1 and T2 when compared to T3. Net nitrogen mineralized in T2 was found to be negative (-0.30), indicating immobilization of N and the availability of organic matter for microbial growth. Biomass C, as a proportion of total soil C, serves as a proxy for soil quality (Jenkinson and Ladd, 1981). Acid phosphatase and alkaline phosphatase of treatment plots T1, T2 and T4 were higher than T3 (Table 2). The physio-chemical properties of soil can influence the respiration rate and enzyme activities (Martinez and Tabatabai, 2001). Application of organic manures significantly increased phosphatase activity and mineral fertilizers reduced phosphatase activity as observed by Sarapatka (2003). In present observation, dehydrogenase activity of treatment plots was marginally similar (Table 2). Farmyard manure application enhances dehydrogenase activity but fertilizer or chemical treatment doesn't inhibit the same (Lee *et al*., 2000).

In conventionally managed plot T3, there was not much difference in the microbial counts such as bacteria and fungi (Table 3). However, there appeared significant difference in the population of microorganisms that have role in plant growth promotion such as siderophore producers, pseudomonads and antagonistic bacteria. It might be due to the inoculation of such bacteria to the fields at the time of sowing (Table 1) or the nutrients from the application of composts and crop-residues might have provided an environment for enhancement of beneficial groups of bacteria. Unfortunately, limited information exists as to the extent and activity of microorganisms on surface exposed residues themselves. However, it would be expected that significant transformations of nutrients might take place, including mobilization and immobilization as well as gaseous evolution due to application of crop residues (Schoenau and Campbell, 1996). Changes in microbial community in soils take time to develop, since they are a result of complex process and interactions in soil and three to six years are often needed to effect significant, visible changes. Three successive years of organic matter addition were needed to achieve significant disease suppression (Davis *et al*., 1996). Fortunately, just as it takes time to change the soil structure and community, the benefits are also long-lived, potentially lasting for years. It may be noted that much less than 20% of the microbial population that may live in the soil can be cultured in laboratory media (Ward *et al*., 1990).

The nutrient status of T1 and T2 was more when compared to T3 (Table 4). However this does not mean, that crops in these two plots have access to more N and P. Nutrients when added as biomass are not in available form for crops unless mineralized by microbial activity and only a small portion

of it is recovered by crop (Thonnissen *et al*., 2000). There was not much variation in OC content across the four treatments. Increase in soil OC content can be due to application of organic manures or higher crop residue fall to soil. Sharma *et al*. (1984) observed an increase in soil OC content with application of inorganic fertilizers and farmyard manure.

Characterization of Sustainability Indices of Soil Quality

The application of inorganic and organic nutrients improved soil health and thereby increased the yield of T1 and T2 similar to T3 (where chemicals were applied) and T4 (where chemicals and farm waste was applied). T1 and T2 that received plant biomass, compost and microorganisms as source of nutrients showed substantially more N (15-29%) and P (17-23%), than that was added to T3, (Table 4) largely as chemical fertilizers (Rupela *et al*., 2005). In all four treatments, nutrient, biological, microbial and crop indices were calculated. The biological, microbiological, nutrient and crop indices were 1.07, 1.09, 1.11 and 1.00 (Table 6), respectively for treatment T2, with a sustainability index of 2.29 (Fig. 2). In T3, the sustainability index was 1.56 and all four indices were lower than the least sustainability index (Fig. 2). Recent report by Kang *et al*. (2005) showed sustainability index of 2.2, where farmyard manure and green manure was used in rice-wheat system, where indices were calculated using three parameters biological (that included biological and microbial), nutrient and crop index unlike our studies, where biological and microbial indices were used separately for calculating the sustainability index. Abiotic characteristics such as pH, cation exchange capacity, moisture content, temperatures etc. allow a better understanding of the physical and biochemical data obtained and support the final evaluation of soil quality (Filip, 1998). Though in this study we characterized few physical parameters they were not used to derive the sustainability values. As soils vary widely in biological and microbiological activity, the parameters studied here can be used as components of a universal composed index for determining soil quality in relation to plant growth.

Agricultural practices such as incorporation of crop residues have a direct impact on soil health and crop productivity. These practices influence nutrient availability, release of biologically active substances from both crop residues and soil microorganims and suppress root diseases and pests (Van Bruggen, 1995, Bailey and Lazarovits, 2003). Although the development of alternative agricultural systems is generally considered important, it is not clear which practices will improve sustainability and maintain adequate productivity. Field studies of the four different crop husbandry systems showed the great potential of application of microbial inoculants (technology) in low input agricultural practice and environmental pollution abatement for non-use of chemical fertilizers and pesticides. From the present study, it was apparent that plant biomass was the engine of crop-productivity mediated by biological processes that enhanced soil fertility and productive (crop yield) potential of soil.

Acknowledgments

We thank Mr. VP Prasanth, Scientific Officer, ICRISAT for statistical assistance. Doctoral fellowship to Hameeda B by Jawaharlal Nehru Memorial Fund, New Delhi is gratefully acknowledged.

References

Anderson, J.P.E. and K.H. Domsch, 1978. A physiological method for the quantitative measurement of microbial biomass in soils. Soil Biol. Biochem., 10: 215-221.

Bailey, K.L. and G. Lazarovits, 2003. Suppressing soil-borne diseases with residue management and organic amendments. Soil Till. Res., 72: 169-180.

Biederbeck, V.O., R.P. Zentner and C.A. Campbell, 2005. Soil microbial populations and activities as influenced by legume green fallow in a semiarid climate. Soil Biol. Biochem., 37: 1775-1784.

Casida, L.E., D.A. Klein and T. Santoro, 1964. Soil dehydrogenase activity. Soil Sci., 98: 371-376.

Correa, J.D., M.L. Barrios and R.P. Galdona, 2004. Screening for plant growth-promoting rhizobacteria in *Chamaecytisus proliferus* (tagasaste), a forage tree-shrub legume endemic to the Canary Islands. Plant Soil, 266: 75-84.

Dalal, R.C., K.L. Sahrawat and R.J.K. Myers, 1984. Inclusion of nitrate and nitrite in the Kjeldahl nitrogen determination of soils and plant materials using sodium thiosulphate. Comm. Soil Sci. Plant Anal., 15: 1453-1461.

Davis, J.R., O.D. Huisman, D.J. Westermann, SL. Hafez, D.O. Everson, L.H. Sorensen and A.T. Schneider, 1996. Effects of green manures on *Verticillium* wilt of potato. Phytopathology, 86: 443-453.

Delate, K. and C.A. Cambardell, 2004. Organic production: Agroecosystem performance during transition to certified organic grain production. Agron J., 96: 1288-1298.

Eivazi, F. and M.A. Tabatabai, 1977. Phosphatases in Soil. Soil Biol .Biochem ., 9: 167-172.

El-Swaify, S.A., P. Pathak, T.J. Rego and S. Singh, 1985. Soil management for optimized productivity under rainfed conditions in the semi-rid tropics. Adv. Soil Sci., 1: 1-63.

Filip, Z.K., 1998. Soil quality assessment: An ecological attempt using microbiological and biochemical procedures. Adv. Geo. Ecol., 31: 21-27.

Gyaneshwar, P., G. Naresh Kumar and L.J. Parekh, 1998. Effect of buffering on the P-solubilizing ability of microorganisms. World J. Microbiol. Biotechnol., 14: 669-673.

Halvorson, J.J., J.L. Smith and R.I. Papendick, 1996. Integration of multiple soil parameters to evaluate soil quality: A field example. Biol. Fertil. Soils, 21: 207-214.

Hameeda, B., O.P. Rupela, Gopal Reddy and K. Satyavani, 2006. Application of plant growth-promoting bacteria associated with composts and macrofauna for growth promotion of pearl millet (*Pennisetum glaucum* L.) Biol. Fertil. Soils. (In Press).

Jenkinson, D.S. and J.N. Ladd, 1981. Microbial Biomass in Soil: Measurement and Turnover. In Soil Biochemistry. Paul, E.A. and J.N. Ladd, Marcel and Dekker (Eds.). New York, USA., pp: 415-471.

Jenkinson, D.S., 1988. The Determination of Microbial Biomass Carbon and Nitrogen in Soil. In Advances in Nitrogen Cycling in Agricultural Ecosystems. Wilson, J.R. (Ed.). CAB International, Wallingford, pp: 368-386.

Kang, G.S., V. Beri, O.P. Rupela and B.S. Sidhu, 2005. A new index to assess soil quality and sustainability of wheat based cropping systems. Biol. Fertil. Soils, 41: 389-398.

Lee, K.K., M. Vikram Reddy, D. Balaguravaiah, J.V.D.K. Kumar Rao, S.P. Wani, K.P.C. Rao and N. Trimurthulu, 2000. Effect of Soil Management on Soil Microorganisms. In Management of Tropical Agroecosystems and The Beneficial Soil Biota. Vikram Reddy, M. (Ed.). Oxford and IBH Co. Pvt. Ltd., pp: 153-164.

Martinez, A.V. and M.A. Tabatabai, 2001. Tillage and residue management effects on arylamidase activity in soils. Biol. Fertil. Soils, 34: 21-24.

Nannipieri, P., S. Grego and B. Ceccanti, 1990. Ecological Significance of Biological Activity. In. Soil biochemistry. Eds.Bollang, J.M. and G. Stotzky. Marcel Dekker, Inc, New York, pp: 293-355.

OECD (Organization for Economic Co-operation and Development), 1999. Microorganisms as Indicators of Soil Health. http://www2.dmu.dk/1_viden/2_Publikationer/pdf, accessed on 2.2.04

Okalebo, J.R., K.W. Gathua and P.L. Woomer, 1993. Laboratory Methods of Soil and Plant Analysis: A Working Manual, Tropical Soil Biology and Fertility Program. Nairobi, Kenya.

Pankhurst, C.E., B.G. Hawke, H.J. McDonald, C.A. Kirkby, J.C. Buckerfield, P. Michelsen, K.A. O'Brien, V.V.S.R. Gupta and B.M. Doube, 1995. Evaluation of soil biological properties as potential bioindicators of soil health. Aust. J. Exp. Agric.,. 35: 1015-1028.

Pare, T., E.G. Gregorich and S.D. Nelson, 2000. Mineralization of nitrogen from crop residues and N recovery by maize inoculated with vesicular arbuscular mycorrhizal fungi. Plant Soil, 218: 11-20.

Parr, J.F., R.I. Papendick, S.B. Hornick and R.E. Meyer, 1992. Soil quality: Attributes and relationship to alternative and sustainable agriculture. Am. J. Alter. Agric., 7: 5-11.

Richardson, A.E. and P.A. Hadobas, 1997. Soil isolates of *Pseudomonas* spp. that utilize inositol phosphates. Can. J. Microbiol., 43: 509-516.

Rupela, O.P., S. Gopalakrishnan, M. Krajewski and M. Sriveni, 2003. A novel methods for the identification and enumeration of microorganisms with potential for suppressing fungal plant pathogens. Biol. Fertil. Soils, 39: 31-134.

Rupela, O.P., C.L.L. Gowda, S.P. Wani and B. Hameeda, 2005. Evaluation of Crop Production Sytems Based on Locally-available Biological Inputs. In Biological Approaches to Sustainable Soil Sytems. Ed. Uphoff, N. CRC Press, Boca Raton, Florida, USA., pp: 501-515.

Sarapatka, B., 2003. Phosphatase activities (ACP, ALP) in agroecosystem soils. http://diss.epsilon.slu.se/archive/pdf. Accessed on 5.12.2004.

Schoenau, J.F. and C.A. Campbell, 1996. Impact of crop residues on nutrient availability in conservation tillage systems. Can. J. Plant Sci., 76: 621-626.

Schwynn, B. and J.B. Neilands, 1987. Universal chemical assay for detection and determination of siderophores. Anal. Biochem., 169: 47-56.

Sidhu, B.S., O.P. Rupela, V. Beri and P.K. Joshi, 1998. Sustainability Implications of Burning Rice- and Wheat-straw in Punjab. Economic Political Weekly, pp: 163-168.

Sharma, K.N., B. Singh, D.S. Rana, M.L. Kapur and J.S. Sodhi, 1984. Changes in fertility status as influenced by continuous cropping and fertilizer application. J. Agric. Sci., 102: 215-218.

Suzuki, C., T. Kunito, T. Aono, C.T. Liu and H. Oyaizu, 2005. Microbial indices of soil fertility. J. Applied Microbiol., 98: 1062-1074.

Thonnissen, C., D.J. Midmore, J.K. Ladha, D.C. Olk, and U. Schmidhalter, 2000. Legume decomposition and nitrogen release when applied as green manures to tropical vegetable production systems. Agron. J., 92: 253-260.

Van Bruggen, A.H.C., 1995. Plant disease severity in high-input compared to reduced input and organic farming systems. Plant Dis., 79: 976-984.

Vessey, J.K., 2003. Plant growth promoting rhizobacteria as biofertilizers. Plant Soil, 255: 571-586.

Wani, S.P., P. Pathak, L.S. Jangawad, H. Eswaran and P. Singh, 2003. Improved management of Vertisols in the semiarid tropics for increased productivity and soil carbon sequestration. Soil Use Manage., 19: 217-222.

Ward, D.M., R. Weller and M.M. Bateson, 1990. 16S rRNA sequences reveal numerous uncultured microorganisms in a natural community. Nature, 345: 63-65.