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# Assessment of Soil Quality and Identification of Parameters Influencing System Yield under Long-term Fertilizer Trial

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Yield sustainability issues are always related to soil quality, its assessment is very vital. Thus, a long-term experiment (after 31st cycle) was targeted to recognise the soil indicators related to the system productivity of rice-wheat. To achieve the objective, system productivity was calculated and it was observed that treatments supplemented with organic residues were more productive (11.6-12.2 t $ha^{-1}$). Soil qualities under each of the treatments were assessed by integrating the sensitive physical, chemical and biological parameters. All the soil parameters were improved under the treatments supplemented with organic residues. The soil quality index (SQI) was 0.26 for control ($T_1$) and 0.59-0.63 for the integrated treatments ($T_6$, $T_8$ and $T_{10}$). The SQI was highly correlated ($R^2$=0.928) with the system yield. The soil factors like electrical conductivity, available phosphorus, soil organic carbon, porosity, microbial biomass carbon and dehydrogenase activity are identified as the key variables affecting the yield of the rice-wheat cropping system under long-term fertilizer trial.

**Key words:** Organic residues, system yield, soil quality, long-term experiment

Yield sustainability of any agricultural system is one of the important issues in all the countries and intensive agricultural practices are thought to decline the efficiency of the soils to respond better in terms of yield. The issue of yield sustainability is largely related to the soil quality and thus the appraisal of soil quality and its change is a primary marker whether the yields are sustainable or not (Masto *et al*. 2007). In South Asia, the rice-wheat cropping system is a central agricultural production system to encounter the in-creasing food demand. In recent times, a plateau in productivity of the rice-wheat system appeared in cultivated tropical regions, possibly due to fatigued exploitation of natural resource base (Ladha *et al*. 2003). Specific spatial assessment and monitoring of the limitations of soil nutrient uptake and crop yield at regional scales is needed to identify the problem areas as a context for making strategic agronomic decisions. Sustainability of yield is facing a serious challenge and thus a combined approach is required in which soil biological, chemical and physical attributes and their interactions are assessed (Costantini *et al*. 2016). An assessment of the soil productivity by using a soil index could provide key information to improve strategies and effective techniques for the future to achieve sustainable agriculture (Khaki *et al*. 2017). A change in soil parameters usually takes a long time to appear. Long-term experiments are the best means to study the relation of crop yield and the changes in the soil property which subsequently will help to formulate strategies for maintaining the soil quality as well as sustainable yields. Thus, a long-term experiment (started in 1984-1985) was targeted with the objective to find out the soil factors or indicators responsible for yield sustainability over the years.

## Materials and Methods

### *Site description*

This field experiment was es-tablished in 1984 at the Bihar Agricultural College Research Farm (25°23′N, 87°07′E, 37.19 m above mean sea level), Bhagalpur, Bihar, India under the network project

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research program of the Project Directorate on Farming System Research, Modipuram. The soil is Ustochrept clayey soil with following properties: pH 7.40, electrical conductivity 0.23 dS $m^{-1}$, organic carbon 4.6 g $kg^{-1}$, available N 194 kg $ha^{-1}$, available P 10.1 kg $ha^{-1}$ and available K 128.6 kg $ha^{-1}$.

*Experimental details*

The experiment was laid out in randomized block design with 4 replications consisting of 12 treatment combinations *viz*., control ($T_1$); 50% rec-ommended dose of fertilizers (RDF) to both rice and wheat ($T_2$); 50% RDF to rice and 100% RDF to wheat ($T_3$); 75% RDF to both rice and wheat ($T_4$); 100% RDF to both rice and wheat ($T_5$); 50% RDF + 50% N through farmyard manure (FYM) to rice and 100% RDF to wheat ($T_6$); 75% RDF + 25% N through FYM to rice and 75% RDF to wheat ($T_7$); 50% RDF + 50% N through wheat straw to rice and 100% RDF to wheat ($T_8$); 75% RDF + 25% N through wheat straw to rice and 75% RDF to wheat ($T_9$); 50% RDF + 50% N through green leaf manure (GLM) (*Sesbania aculeata*) to rice and 100% RDF to wheat ($T_{10}$); 75% RDF + 25% N through (GLM) to rice and 75% RDF to wheat ($T_{11}$); farmer's fertilizers practice to rice and wheat (70 kg N + 13.2 kg P + 8.3 kg K $ha^{-1}$) ($T_{12}$). The recommended dose of fertilizers (N: P: K) for rice (cv. Sita) and wheat (cv. UP-262) was 80:17.6:33.2 kg $ha^{-1}$ and 120:26.4:33.2 kg $ha^{-1}$, respectively. The required amount of FYM, wheat straw and *Sesbania* was applied 3 weeks before rice transplanting as per treatment to substitute a specified amount of N. The FYM, wheat straw and *Sesbania* used in this experiment contain 0.50, 0.65 and 0.53% N, respectively.

*Analytical methods*

Grain yield were recorded at the end of 31st cycle (2014-2015), simultaneously soil samples was collected after harvest of rice for the calculation of system productivity and soil quality, respectively. Soil organic carbon (SOC) was determined by wet oxidation method (Walkley and Black 1934); Available N by alkaline potassium permanganate distillation method; available P using 0.5 *M* $NaHCO_3$ as extractant; available K with neutral normal ammonium acetate. Soil dehydrogenase activity was determined by the method of Klein *et al*. (1971). Microbial biomass carbon (MBC) was measured by the fumigation and extraction method (Vance *et al*. 1987). Phosphatase activity was calculated as per the method outlined by Tabatabai and Bremner (1969). Bulk density (BD) was measured by core method, mean weight diameter using wet sieving technique (Kemper and Rosenau 1986) and the maximum water holding capacity (WHC) was determined by equilibrating the soils with water through capillary action in a keen-Rackzowski box (Baruah and Barthakur 1999).

*Assessment of soil quality*

For assessment of soil quality, critical parameters were identified to study the sustainability of system yield (rice and wheat) under long-term experiment. Then the soil properties were identified which could explain the selected management goal. The contribution of the individual soil property to accomplish the goal or function was included by assigning the respective indicator weights derived by using statistical tool like principal component analysis (PCA) using SPSS 16.0 software (Chicago, USA). All the indicators values (x) were converted into unit less scores (Y) (0 to 1) based on critical values (Table 2) and using the following equation:

(1) LSF (Y) = (x - s) / (t - s) for soil property considered under "More is better"

(2) (Y) = 1- [(x - s) / (t - s)] for soil property considered under "Less is better"

Finally all indicator scores were integrated into principal component analysis based single SQI with the help of the equation given below:

$$SQI = \sum_{i=1}^{n} Wi * Si$$

where, W is the PCA weighing factors and S is the indicator score. The equation was finally normalized to get a maximum score of one.

## Results and Discussion

*Rice equivalent yields or system yield*

Data collected over the 31 years showed that the rice equivalent yield was significantly higher (12.2 t $ha^{-1}$) with the application of 50% mineral NPK fertilizer supplemented with 50% N through FYM ($T_6$) as compared to the recommended level of NPK fertilizer ($T_5$-10.6 t $ha^{-1}$). The results revealed that balanced fertilization improves the grain yield (Li *et al*. 2010) and balance nutrition facilitates the translocation of nutrients to the economic part of the crop (Yang *et al*. 2004). The practice adopted usually by the farmers showed a lower rice equivalent yield of 7.03 t $ha^{-1}$ signifying the need of implementing integrated nutrient management options (Table 1).

**Table 1.** Effect of long-term fertilization (31st cycle) on rice equivalent yield and soil quality indicators

| Treatments | REY | BD | POR | MWD | pH | EC | SOC | N | P | K | DHA | MBC | Alk-P | Acid-P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $T_1$ | 2.03 | 1.48 | 43.7 | 0.99 | 7.38 | 0.27 | 0.34 | 116 | 13.9 | 106 | 12.5 | 124 | 160 | 24.5 |
| $T_2$ | 5.63 | 1.47 | 44.1 | 1.08 | 7.36 | 0.34 | 0.39 | 142 | 19.9 | 112 | 14.3 | 155 | 223 | 28.1 |
| $T_3$ | 8.08 | 1.43 | 45.6 | 1.01 | 7.34 | 0.35 | 0.45 | 155 | 34.1 | 119 | 15.4 | 166 | 155 | 35.7 |
| $T_4$ | 7.94 | 1.43 | 45.6 | 1.04 | 7.32 | 0.34 | 0.44 | 162 | 36.8 | 122 | 15.8 | 176 | 236 | 43.9 |
| $T_5$ | 10.66 | 1.39 | 47.1 | 1.09 | 7.30 | 0.33 | 0.54 | 170 | 41.5 | 129 | 16.9 | 185 | 260 | 36.0 |
| $T_6$ | 12.23 | 1.37 | 47.9 | 1.15 | 7.27 | 0.28 | 0.77 | 231 | 49.8 | 172 | 28.7 | 289 | 268 | 57.9 |
| $T_7$ | 11.21 | 1.32 | 49.8 | 1.07 | 7.27 | 0.32 | 0.74 | 214 | 44.6 | 150 | 20 | 229 | 295 | 62.4 |
| $T_8$ | 11.58 | 1.36 | 48.2 | 1.18 | 7.25 | 0.33 | 0.76 | 224 | 47.5 | 195 | 22.5 | 265 | 215 | 56.1 |
| $T_9$ | 10.82 | 1.34 | 49.0 | 1.1 | 7.29 | 0.30 | 0.72 | 205 | 42.9 | 176 | 17.6 | 220 | 233 | 60.6 |
| $T_{10}$ | 11.96 | 1.37 | 47.9 | 1.13 | 7.26 | 0.32 | 0.77 | 229 | 48.8 | 171 | 23.5 | 246 | 207 | 45.0 |
| $T_{11}$ | 11.15 | 1.35 | 48.6 | 1.1 | 7.29 | 0.26 | 0.73 | 212 | 45.6 | 152 | 18.6 | 227 | 270 | 37.5 |
| $T_{12}$ | 7.03 | 1.44 | 45.2 | 1.01 | 7.38 | 0.26 | 0.47 | 142 | 27.3 | 117 | 11.4 | 152 | 214 | 27.5 |
| *CD* (*P = 0.05*) | 0.81 | 0.03 | 0.9 | 0.04 | 0.04 | 0.02 | 0.02 | 5.6 | 2.19 | 5.8 | 0.061 | 6.1 | 7.13 | 2.92 |

$T_1$ – control (no fertilizer no organic ma-nure); $T_2$ – 50% recommended dose of fertilizers (RDF) to both rice and wheat; $T_3$ – 50% RDF to rice and 100% RDF to wheat; $T_4$ – 75% RDF to both rice and wheat; $T_5$ – 100% RDF to both rice and wheat; $T_6$ – 50% RDF + 50% N through FYM to rice and 100% RDF to wheat; $T_7$ – 75% RDF + 25% N through FYM to rice and 75% RDF to wheat; $T_8$ – 50% RDF + 50% N through wheat straw to rice and 100% RDF to wheat; $T_9$ – 75% RDF + 25% N through wheat straw to rice and 75% RDF to wheat; $T_{10}$ – 50% RDF + 50% N through green leaf manure (GLM) to rice and 100% RDF to wheat; $T_{11}$ – 75% RDF + 25% N through GLM to rice and 75% RDF to wheat; $T_{12}$ – farmer's fertilizers practice to rice and wheat (70 kg N + 13.2 kg P + 8.3 kg K $ha^{-1}$). REY- Rice equivalent yield (t $ha^{-1}$); BD- bulk density (Mg $m^{-3}$); POR- porosity (%); MWD- mean weight diameter (mm); EC- electrical conductivity; SOC- Soil organic carbon (%); N- available nitrogen (kg $ha^{-1}$); P- available phosphorus (kg $ha^{-1}$); K- available potassium (kg $ha^{-1}$); DHA- dehydrogenase activity (µg TPF $g^{-1}$ soil $h^{-1}$); MBC- microbial biomass carbon (µg $g^{-1}$ soil); Alk-P- alkaline phosphatase activity (µg PNP $g^{-1}$ soil $h^{-1}$); Acid-P- acid phosphatase activity (µg PNP $g^{-1}$ soil $h^{-1}$).

**Table 2.** Soil quality indicators and scoring functions

| Indicator | Scoring curve | Lower threshold (s) | Upper threshold (t) | Reference |
|---|---|---|---|---|
| Porosity (%) | Optimum | 20 | 80 | Karlen *et al.* (1994) |
| Soil organic carbon (%) | More is better | 0 | 0.8 | Rao (1995) |
| Nitrogen (kg $ha^{-1}$) | More is better | 0 | 560 | ISSS (2009) |
| Phosphorus (kg $ha^{-1}$) | More is better | 0 | 50 | ISSS (2009) |
| MBC (mg $kg^{-1}$) | More is better | 0 | 300 | Kumar, 2016; Masto *et al.* (2007) |
| Acid phosphatase activity (µg PNP $g^{-1}$ oven dry soil $h^{-1}$) | More is better | 0 | 80 | AICRP-IFS (2015) (Undisturbed ecosystem) |
| MWD (mm) | More is better | 0 | 40 | Gelaw *et al.* (2015) |
| pH | Optimum | 6.0 | 9.0 | US Salinity Laboratory Staff (1954) |
| EC (dS $m^{-1}$) | Optimum | 0 | 2.0 | Rhoades (1982) |
| DHA (µg TPF $g^{-1}$ oven dry soil $h^{-1}$) | More is better | 0 | 50 | Masto *et al.* (2007) |

*Physical, chemical and biological soil parameters*

The BD was lowest in the soil treated with organic materials (1.37, 1.36 and 1.37 Mg $m^{-3}$ in $T_6$, $T_8$ and $T_{10}$, respectively). Porosity of the soils ranged from 43.7% in control and 47.9% with the application of 50% mineral NPK supplemented with 50% N through FYM ($T_6$). Mean weight diameter recorded in integrated nutrient management were 1.15, 1.18 and 1.13 mm in $T_6$, $T_8$ and $T_{10}$, respectively). Application of organic residues improved the physical properties of soils which is due to the increase in SOC. The SOC improves the aggregation and thus decreases the BD of soils. The soil pH and EC did not differed much. The SOC in soil ranged from 3.4 g $kg^{-1}$ in control to 5.4-7.4 g $kg^{-1}$ in treatments supplemented with organic residues. Higher SOC in soils may be due to the greater root biomass added through better crop growth as reflected in the rice equivalent yield (Bhattacharyya *et al*. 2013). The maximum available N (231.4 kg $ha^{-1}$) was noticed in treatment: 50% N through FYM in rice ($T_6$) followed by green manuring, $T_{10}$ (229.2 kg $ha^{-1}$) and wheat straw, $T_8$ (224.8 kg $ha^{-1}$). Increase in the available P in integrated nutrient management treatments might be due to higher degree of mineralization with subsequent formation of different organic acids which in turn, caused a higher degree of phosphate solubilization. Substantial decrease in available K status has been observed in the control, the plots receiving inorganic fertilization ($T_2$-$T_5$) and the plots under farmers' practice ($T_{12}$). Application of organic amendments induced a positive effect on the availability of K. Data on dehydrogenase activity in soils showed a significant effect of different fertilizer treatments. The dehydrogenase activity ranged from 12.5 ìg TPF $g^{-1}$ $h^{-1}$ in control treatment to 28.7 µg TPF $g^{-1}$ $h^{-1}$ in the treatment receiving 50% NPK through chemical fertilizers+50% N through FYM in rice. The dehydrogenase was increased by FYM applications as compared to straw treatment might be due to more easily decomposable components of FYM on the metabolism of soil microorganisms (Chaudhury *et al*. 2005). Inputs of readily metabolizable C and N in organic manure are the most important factors contributing to the MBC increase in the integrated treatments (246.8-289.4 mg $kg^{-1}$) (Wang *et al*. 2011). Alkaline phosphatase and acid phosphatase activity were also increased similarly as in case of MBC (Table 1).

*Soil quality assessment*

Quality indicators are normalized on a scale from 0 to 1 using the linear scoring function. The thresholds of each parameter were assigned as presented in table 2. These limits or thresholds are taken from the experiments conducted under stable ecosystems like best managed systems, forest areas and from the standards set or recognised under tropical regions.

Principal component analysis based soil quality indices were worked out as presented in table 3. The soil variables having significant differences between treatments were included in the PCA. The highly weighted variables under PC-1 are porosity, SOC, P and MBC. It is advisable to take SOC in the equation as it is an important indicator under tropical regions and can also represent the available N content of the soil (*r* = 0.986**) (Table 4). Under PC-2, EC and DHA are highly weighted. The final normalized PCA based soil quality equation is:

SQI = 0.23 S (POR) + 0.23 S (P) + 0.23 S (MBC) + 0.23 S (SOC) + 0.05 S (EC) + 0.05 S (DHA)

Where, S is the score for the individual variables and the coefficients are obtained from PCA. The SQI obtained using the PCA were 0.63, 0.60 and 0.59 for $T_6$, $T_8$ and $T_{10}$, respectively (Fig. 1). The control system is degraded and the integrated treatments were sustaining according to PCA-SQI. Once the minimum data set are established there may be no need for testing a broad array of other indicators to assess soil quality over time. Organic residues improved the nutrient status, microbial parameter which was clearly reflected in the soil quality index.

**Table 3.** Performance of soil quality indicators in terms of factor loading/eigen vector values in principal component analysis to sort out the parameters responsible for crop / system productivity

| PCs | PC1 | PC2 |
|---|---|---|
| Eigen value | 8.88 | 1.97 |
| % of Variance | 68.32 | 15.12 |
| Cumulative % | 68.32 | 83.44 |
| **Factor loading/eigen vector** | | |
| BD | -0.967 | -0.039 |
| POR | 0.967 | 0.039 |
| MWD | 0.729 | 0.471 |
| pH | -0.944 | 0.278 |
| EC | 0.276 | 0.621 |
| SOC | 0.867 | -0.458 |
| N | 0.890 | -0.431 |
| P | 0.922 | -0.259 |
| K | 0.841 | -0.442 |
| DHA | 0.706 | 0.601 |
| MBC | 0.873 | 0.415 |
| Alk-P | 0.672 | 0.056 |
| Acid-P | 0.836 | 0.287 |

PCA-SQI= 0.68 POR + 0.68 P + 0.68 MBC+0.68 SOC+0.15 EC + 0.15 DHA

Normalized PCA-SQI = [0.68 POR + 0.68 P + 0.68 MBC +0.68 SOC + 0.15 EC + 0.15 DHA] /3.02

= 0.23 POR + 0.23 P + 0.23 MBC +0.23 SOC + 0.05 EC + 0.05 DHA

**Table 4.** Inter-correlations between highly weighted variablesunder different PCs

| PC1 | POR | SOC | N | P | K | MBC |
|---|---|---|---|---|---|---|
| SOC | 0.790** | | | | | |
| N | 0.839** | 0.986** | | | | |
| P | 0.852** | 0.918** | 0.950** | | | |
| K | 0.806** | 0.935** | 0.928** | 0.844** | | |
| MBC | 0.822** | 0.603* | 0.600* | 0.687* | 0.546 | |
| ACP | 0.845** | 0.575 | 0.600* | 0.657* | 0.594* | 0.819** |

| PC 2 | MWD | pH | EC |
|---|---|---|---|
| pH | -0.570 | | |
| EC | 0.317 | -0.155 | |
| DHA | 0.837** | -0.477 | 0.371 |

**Correlation is significant at the *p<0.01* * Correlation is significant at the *p<0.05* level

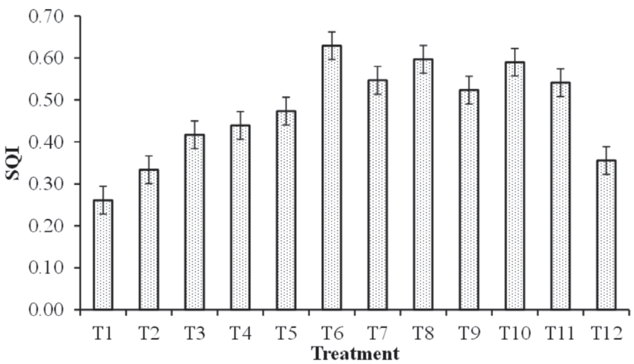


**Fig. 1.** Principal component Analysis based Soil Quality Index

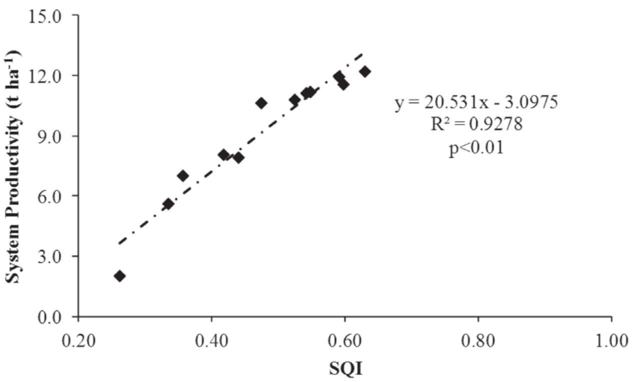


**Fig. 2.** Relation between SQI and end point variable (Crop yield)

*Correlation of soil quality* vs *rice equivalent yield*

The function of maintaining crop productivity was highly correlated with the system productivity. It was clearly revealed that the crop productivity increased with increasing soil quality index (Fig. 2).

## Conclusions

Soil quality research has started gaining momentum during the last decade in India, considering its distinctiveness of the study; but inconsistent soil environment existing in the rice-wheat system due to difference in management practices of India demands its essentiality to identify the key soil properties driving the productivity of systems. In the current study, indicators *viz.,* electrical conductivity, available P, soil organic carbon, porosity, microbial biomass carbon and dehydrogenase activity were identified and can be recommended for periodical assessment of soil quality under subtropical humid Ustochrept clayey soil. Organic residues (SQI value: FYM-0.63; wheat straw-0.60; green manure- 0.59) along with 50% recommended dose of fertilizers were found to be viable options in maintenance of soil quality and achieving the sustainable productivity in long run but with assured availability of these residues in the specific locations. Further, the use of this site-specific index can help planners and decision makers to evaluate which management practice is most sustainable and *vice-versa* in a given situation.

## References

AICRP-IFS (2015) Annual Report of Integrated Farming System submitted to Indian Institute of Farming System Research, Modipuram, Meerut, UP, India.

Baruah, T.C. and Barthakur, H.P. (1999) *A Text Book of Soil Analysis*. New Delhi: Vikas Publishing House Pvt. Ltd.

Bhattacharyya, R., Pandey, S.C., Bisht, J.K., Bhatt, J.C., Gupta, H.S., Tuti, M.D., Mahanta, D., Mina, B.L., Singh, R.D., Chandra, S., Srivastva, A.K. and Kundu, S. (2013) Tillage and irrigation effects on soil aggregation and carbon pools in the Indian sub-himalayas. *Agronomy Journal* **105**, 101-112.

Chaudhury, J., Mandal, U.K., Sharma, K.L., Ghosh, H. and Mandal, B. (2005) Assessing soil quality under long term rice based cropping system. *Communications in Soil Science and Plant Analysis* **36**, 1141-1161.

Costantini, E. A. C., Branquinho, C., Nunes, A., Schwilch, G., Stavi, I., Valdecantos, A. and Zucca, C. (2016) Soil indicators to assess the effectiveness of restoration strategies in dryland ecosystems. *Solid Earth* **7**, 397-414.

Gelaw, A.M., Singh, B.R. and Lal, R. (2015) Soil quality indices for evaluating small holder agricultural land uses in Northern Ethiopia. *Sustainability* **7**, 2332-2337.

ISSS (2009) *Fundamentals in Soil Science*. Indian Society of Soil Science, New Delhi, India.

Karlen, D.L. and Stott, D.E. (1994) A framework for evaluating physical and chemical indicators of soil quality. In Defining Soil Quality for a Sustainable Environment (J.W. Doran, D.C. Coleman, D.F. Bezdick and B.A. Stewart, Eds), Madison, WI: SSSA Special Publication No. 35, ASA and SSSA, pp. 53-72.

Kemper, W.D. and Rosenau, K. (1986) Size distribution of aggregates. In *Methods of Soil Analysis* (A. Klute, Ed.), Part 1, Physical and Mineralogical Methods, American Society of Agronomy, Madison, WI, pp. 425-442.

Khaki, B.D., Honarjoo, N., Davatgar, N., Jalalian, A. and Golsefidi, H.T. (2017) Assessment of two soil fertility indexes to evaluate paddy fields for rice cultivation. *Sustainability* **9**, 1299, doi:10.3390/su9081299

Klein, D.A., Loh, T.C. and Goulding, R.L. (1971) A rapid procedure to evaluate dehydrogenase activity of soils low in organic matter. *Soil Biology and Biochemistry* **3**, 385-387.

Kumar, A. (2016) Microbial resistance and resilience of balanced fertilized and nanomaterials added soils under heat stress. PG Thesis, submitted to Bihar Agricultural University, Bhagalpur, Bihar, India.

Ladha, J.K., Dawe, D., Pathak, H., Padre, A.T., Yadav, R.L., Singh, B., Singh, Y., Singh, Y., Singh, P., Kundu, A.L., Sakal, R., Ram, N., Regmi, A.P., Gami, S.K., Bhandari, A.L., Amin, R., Yadav, C.R., Bhattarai, E.M., Das, S., Aggarwal, H.P., Gupta, R.K. and Hobbs, P.R. (2003) How extensive are yield declines in long-term rice-wheat experiments in Asia? *Field Crops Research* **81**, 159-180.

Li, Z., Liu, M., Wu, X., Han, F. and Zhang, T. (2010) Effects of long-term chemical fertilization and organic amendments on dynamics of soil organic C and total N in paddy soil derived from barren land in subtropical China. *Soil and Tillage Research* **106**, 268-274.

Masto, R.E., Chhonkar, P.K., Singh, D. and Patra, A.K. (2007) Soil quality response to long term nutrient and crop management on a semi-arid Inceptisols. *Agriculture, Ecosystems and Environment* **118**, 130-142.

Rao, S. (1995) Analysis of soils for available inorganic nutrients. In *Methods of Analysis of Soils, Plants, Water and Fertilisers* (H.L.S. Tandon, Ed.), Fertiliser Development and Cooperation Organisation. New Delhi, India, pp. 13-35.

Rhoades, J.D. (1982) Soluble salts. In *Methods of Soil Analysis* (A.L. Page, R.H. Miller and D.R. Keeney, Eds.), Part 2, 2nd Edition. Agronomy Monograph 9, ASA and SSSA, Madison, WI, pp. 635-655.

Tabatabai, M.A. and Bremner, J.M. (1969) Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry* **1**, 301-307.

US Salinity Laboratory Staff (1954) Diagnosis and improvement of saline and alkali soils. In *Handbook* (L.A. Richards, Ed.), US Department of Agriculture, Vol. 60.

Vance, E.D., Brookes, P.C. and Jenkinson, D.S. (1987) An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry* **19**, 703-707.

Walkley, A. and Black, I.A. (1934) An estimation of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37, 29-38.

Wang,Yi, Tu, C., Cheng, L., Li, C., Gentry, L.F., Hoyt, G.D., Zhang, X. and Hu, S. (2011) Long-term impact of farming practices on soil organic carbon and nitrogen pools and microbial biomass and activity. *Soil and Tillage Research* **117**, 8-16.

Yang, C., Yang, L., Yang, Y. and Ouyang, Z. ( 2004) Rice root growth and nutrient uptake as influenced by organic manure in continu-ously and alternately flooded paddy soils. *Agricultural Water Management* **70**, 67-81.

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