Soil Quality Parameters as Influenced by Management Practices in Rice-Wheat and Maize-Wheat Cropping Systems

Anil Kumar Singh

Indian Council of Agricultural Research, KAB II, IARI Campus, New Delhi – 110012, India, Email aksingh@icar.org.in

Abstract
A long-term experiment was initiated in 2001 to quantify the impact of integrated plant nutrient-water-tillage interactions on soil quality in rice-wheat and maize-wheat cropping systems. The treatments consisted of two tillage, three water regimes and twelve nutrient levels. Various soil physical, chemical and microbiological parameters were monitored periodically using standard procedures. The results indicated that there were significant interactions between tillage, water regimes and nutrient levels in both the cropping systems. Organic carbon and microbial biomass carbon increased in the treatments receiving application of organic manures (particularly FYM), green manure and biofertilizers in conjunction with inorganic fertilizers. Build-up of organic carbon in soil was relatively higher in macro-aggregates compared to micro-aggregates. The 100% inorganic treatment recorded maximum NH_4-N under both the cropping systems. Integrated nutrient management treatments were successful in reducing the amount of applied N leaching down the profile as well as enhancing the availability of other major and micronutrients. Carbon management index (CMI) was significantly higher under integrated sources of nutrients compared to inorganically fertilized treatments. Among the various soil quality indices studied, Linear Weight Additive Soil Quality Index (LWASQI) was the best soil quality index that could quantify the effects of main and interactive effects of all the four factors on the quality of soil.

Key Words
Integrated nutrient management systems, soil health, organic acids, crop residues, labile pools

Introduction
Agricultural production being an integrated interactive effect of soil-water-fertilizer-climate continuum, a judicious and scientific management of this complex system is crucial for enhancing crop productivity on a sustained basis. Among the various inputs, water and fertilizer (nutrients) are considered as the two key inputs making maximum contribution to crop productivity. Efficient management of these two costly inputs together with synergistic interaction with other appropriate production factors is most critical for any crop cultivar to achieve its genetic yield potential. Soil management through tillage can further optimize their use efficiencies. Technologies developed on the principles of eco-friendly and efficient balanced fertilization and based on optimization of nutrient supplies from all the available sources, inorganic and organic, for pre-determined yield targets of the cropping sequences through an efficient combination of soil, water, organic matter, tillage and nutrient management, will provide a prescription for sustainable agricultural development. Since sustainability of agricultural production system has become an issue of national and international concern, one of the options is to assess the soil quality as impacted by the various soil and crop management practices. Hence, the present investigation was undertaken to quantify the interactive effects of tillage, water and nutrient practices on soil quality and crop productivity in rice-wheat and maize-wheat cropping systems.

Materials and Methods
A long term experiment was initiated in 2001 to quantify the integrated plant nutrient-water-tillage interactions in rice-wheat and maize-wheat cropping systems. The treatments consisted of two tillage, three water regimes and twelve nutrient levels. The nutrient treatments were: control (No nitrogen), 75% NPK (75 represents 75 per cent of the recommended dose for nitrogen), 100% NPK, 150% NPK, 75% NPK (25% N substituted by FYM), 100% NPK (25% N substituted by FYM), 150% NPK (25% N substituted by FYM), 100% NPK + green manure (*Sesbania*), 100% NPK (25% N substituted by bio-fertilizers), 100% NPK (25% N substituted by sewage sludge), 100% NPK + crop residues incorporated (of the previous crop), and 100% N through organic sources (50% FYM + 25% biofertilizer + 25% crop residue). In rice, the tillage treatments were puddled (transplanted) and dry seeded (non-puddled) while in maize it was bed planting and conventional flat-bed planting. In wheat, it was conventional tillage and no-tillage treatments. The water regimes were unlimited water availability (continuous submergence in rice, three irrigations in maize and five irrigations in wheat), adequate water availability (one day drainage in rice, two irrigations in maize and

three irrigations in wheat) and limited water availability (three day drainage in rice, one irrigation in maize and three irrigations in wheat). The experiments were laid out in split plot design with three replications. Under both the cropping systems, two tillage, three water management and twelve manurial/fertilizer treatments were allocated to main, sub and sub-sub plots, respectively The experiment was initiated by growing rice in rice-wheat cropping systems and maize in maize-wheat cropping systems during the monsoon *(kharif)* season followed by wheat in the winter *(rabi)* season. Detailed observations on various soil physical and chemical properties, major and micronutrients and microbiological parameters were monitored periodically using standard procedures. Total organic carbon in soil was determined by wet oxidation method (Snyder and Trofymow, 1984). Labile carbon, *i.e*. amount of oxidizable carbon by 333 mM $KMnO_4$ in soil, was determined according to the procedure of Blair *et al.* (1995). Microbial biomass carbon of soil was determined by fumigation-extraction method (Jenkinson and Powlson, 1976). Carbon management index (CMI) under various management practices was computed according to Blair *et al.* (1995).

The soil functions considered for soil quality index were water and solute flow, physical stability, nutrient cycling and crop growth. The minimum data set consisted of twelve soil indicators out of which five soil physical indicators were bulk density, total porosity, mean weight diameter, available water capacity and saturated hydraulic conductivity; five soil chemical indicators were pH, EC, soil nitrate-N, soil ammonium-N and organic carbon and two soil biological indicators were microbial biomass carbon and dehydrogenase activity. All the measured values of each indicator were transformed to scores with one of the three (more is better, less is better or optimum is better) scoring functions. Linear (L) or non-linear (NL) scores were obtained with linear or non-linear interpolations using scoring curves. Integration of scores to develop soil quality index was achieved in two ways. In one approach, equal weights were assigned to scores of all the twelve variables to form Simple Soil Quality Index (SSQI). In the second approach, weights were assigned based on loading factors of Principal Component Analysis and called Weighted Soil Quality Index (WSQI). Additive (A) and multiplicative (M) soil quality indices (SQI) were developed for linear (L) as well as non-linear (NL) scoring using the scored values. A total of eight indices were determined for all the treatments, *viz*., LSASQI, LWASQI, LSMSQI, LWMSQI for linear scores and NLSASQI, NLWASQI, NLSMSQI, and NLWMSQI for non-linear scores.

Results

The results indicated that there were significant interactions between tillage, water regimes and nutrient levels in both the cropping systems. They have been presented in the following sections.

Organic carbon

The puddled and non-puddled treatments in rice also influenced the water and nutrient uptake. Organic carbon and microbial biomass carbon increased in the plots receiving application of organic manures (particularly FYM), green manure and biofertilizers in conjunction with inorganic fertilizers. Compared to non-puddled conditions, puddling was associated with increase in organic carbon content whereas microbial biomass carbon was higher in the non-puddled plots. Under continuous submerged conditions, organic carbon content was enhanced whereas the microbial biomass carbon content was reduced. In rice, the yield of transplanted crop was better than the dry seeded treatments while the water regime treatment of irrigation one day after disappearance of water had a positive impact on soil quality. In maize-wheat cropping system, it was conclusively established that tillage-water-nutrient interactions significantly affected the soil organic carbon content. Among the organic carbon fractions, there was marginal improvement in Walkley and Black (WBC) content in soil under integrated and organic nutrient management treatments in maize-wheat and rice-wheat cropping systems. Improvement in stabilized pools of soil organic carbon (SOC) was not proportional to the applied amount of organic manures. While labile pools of SOC increased with the increase in amount of added manures, apparently, green manure (*Sesbania*) was more effective in enhancing the lability of SOC as compared to farmyard manure and crop residues. The $KMnO_4$-oxidizable SOC proved to be more sensitive and consistent as an index of labile pool of SOC compared to microbial biomass carbon. In rice-wheat, the highest increase in the value of CMI was recorded under 100% organics, which was at par with 100% N + PK + green manure. The substitution of 25% inorganic N by FYM resulted into similar value of CMI as obtained under mineral fertilizers. However, incorporation of crop residues along with 100% N + PK could not improve the CMI with reference to control. In maize-wheat, supplementation of balanced amount of N, P and K either through inorganic fertilizers or integrated sources or organic sources significantly improved the CMI over control. Total soil organic carbon was not affected by tillage and nutrient management practices under these cropping sequences.

Build-up of organic carbon was relatively higher in macro-aggregates compared to soil and micro-aggregates. No-tillage in wheat positively influenced the organic carbon content in soil, macro- and micro-aggregates. In case of rice-wheat system, the effect was higher in the plots receiving 100% organics and followed by the plots receiving 100%N + green manure. In case of maize-wheat system, it was highest in the plots treated with total organics followed by the plots treated with 25% N substituted by FYM. Incubation studies on the soils collected from various treatments under field conditions revealed that carbon mineralization was higher under saturated condition as compared to that under 2.5 cm standing water.

Organic acids

Butyric acid is the dominant acid produced in the rice soil, followed by propionic acid and acetic acids. Farmyard and green manures are associated with enhanced availability of nutrients as these manures generate organic acids, *viz.,* acetic, propionic and butyric, in controlled amounts for a longer duration. However, sewage sludge must be applied to rice soils with caution, as it produced the above three acids, in quantities exceeding threshold limits.

Available nutrient content in soil

The treatments receiving N through inorganic sources only recorded maximum NH_4-N at all the depths, while partial or full substitution of fertilizer with organics substantially reduced the downward translocation of NH_4-N. In case of the water regimes, the wettest water regime (unlimited water availability) treatment maintained highest NH_4-N levels throughout the profile, followed by the adequate water availability treatment and limited water availability under both the cropping systems. Under both the cropping systems, NO_3-N was more under the plots treated with 100% N+ green manure (GM) followed by 100% N + crop residues. The highest NO_3-N content in the soil, macro- and micro-aggregates in the surface layer was found under minimum water regimes under both the cropping systems, while NO_3-N content was highest in the unpuddled soil in the rice-wheat and in bed planted soil of maize-wheat system. Application of N through organics or integrated sources showed relatively higher amount of available P under both the cropping systems. Puddling in rice maintained a higher amount of available P as compared to unpuddled soils, whereas conventionally-tilled soil contained higher amount of available P compared to that under bed-planted soil under maize-wheat system. Higher available P content was associated with maximum water regimes followed by optimal and sub-optimal water regimes under both the systems. There was a substantial improvement in available iron (Fe) status in puddled compared to un-puddled soil after harvest of rice. Among the water management treatments, continuous submergence and irrigation after one day after drainage, were equally effective in maintaining available Fe status in soil, which were inferior to irrigation after 3 days of drainage. Available Mn and Ni were depleted as result of continuous submergence particularly under unpuddled condition. These results clearly suggest that intermittent drainage in rice field is not only water saving option but also effective in maintaining adequate fertility status of soil in respect of micronutrient cations.

Physical properties

Under rice-wheat cropping system, percentage of >5 mm sized aggregates were maximum in fully organic and green manure-treated plots. More than 50% of the total aggregates were distributed in the <0.1 mm sized fraction under both rice-wheat and maize-wheat cropping systems. In case of rice-wheat cropping system, percentage of macro-aggregates were more in the unpuddled soils, whereas in case of maize-wheat cropping system, it was more under bed planting. The amount of the macro-aggregates was lowest in the control plots under both the cropping systems. It was highest in the plots treated with total organics, followed by green manuring in the rice-wheat cropping system. But in the maize-wheat, it was highest in the plots treated with total organics followed by the FYM-treated plots.

Soil quality index

The study on the quantification of soil quality indicated that Linear Weight Additive Soil Quality Index (LWASQI) is the best soil quality index among all the eight indices, which could quantify the effects of main and interactive effects of all the four factors on the quality of soil in the best manner. In maize-wheat cropping system, the best treatment was 100% NPK with 25% N substituted by bio-fertilizer, while in rice-wheat system, it was 100% NPK + green manuring and followed by 100% NPK with 25% N substituted by sewage sludge.

Conclusions

Organic materials with wider C/N ratio (e.g. FYM and crop residue) had more impact on relatively stabilized fractions of SOC (quantity), while the same with narrower C/N ratio (e.g. GM) exerted more impact on the active fractions (quality) of SOC. Integrated use of mineral fertilizers and organic manures could improve the soil quality under both the cropping systems as evident from carbon management index. Under tropical conditions, although the optimized tillage, water and integrated nutrient management is the fertility building practice, it does not ensure the protection of carbon sequestered from the environmental oxidation as CO_2 because of the bulk of the captured carbon gets distributed into oxidation-vulnerable macro-aggregates. Integrated use of mineral fertilizers and organic manures were associated with the improvement of soil fertility status in respect of major and micronutrients. The study indicated that Linear Weight Additive Soil Quality Index (LWASQI) was the best soil quality index among all the eight indices, which could quantify the effects of main and interactive effects.

References

Blair GJ, Lefroy RDB, Lisle L (1995) Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Australian Journal of Soil Research* **46**, 1459-1466.

Jenkinson DS, Powlson DS (1976) The effects of biocidal treatment on metabolism in soil. V. A method for measuring soil biomass. *Soil Biology and Biochemistry* **8,** 209-213.

Snyder JD, Trofymow JA (1984) A rapid accurate wet oxidation diffusion procedure for determining organic and inorganic carbon in pot and soil samples. *Communications in Soil Science and Plant Analysis* **15**, 587-597.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.