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Soil quality effects of tillage and residue under rice–wheat cropping on a Vertisol in India

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Abstract

Soil quality in rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping systems is governed primarily by the tillage practices used to fulfill the contrasting soil physical and hydrological requirements of the two crops. The objective of this study was to develop a soil quality index (SQI) based on bulk density (BD), penetration resistance (PR), water stable aggregates (WSA) and soil organic matter (OM) to evaluate this important cropping system on a Vertisol in India. Regression analysis between crop yield and SQI values for various tillage and crop residue management treatments indicated SQI values of 0.84–0.92, 0.88–0.93 and 0.86–0.92 were optimum for rice, wheat and the combined system (rice + wheat), respectively. The maximum yields for rice and wheat were 5806 and 1825 kg ha^{-1} occurred at SQI values of 0.85 and 0.99, respectively. Using zero tillage (ZT) for wheat had a positive effect on soil quality regardless of the treatments used for rice. Regression analyses to predict sustainability of the various tillage and crop residue treatments showed that as puddling intensity for rice increased, sustainability without returning crop residues decreased from 6 to 1 years. When residue was returned, the time for sustainable productivity increased from 6 to 15 years for direct seeded rice, 5 to 11 years with low-intensity puddling (P_1) and 1 to 8 years for high-intensity (P_2) puddling. For sustainability and productivity, the best practice for this or similar Vertisols in India would be direct seeding of rice with conventional tillage and residues returned.

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1. Introduction

The rice–wheat cropping system is one of the oldest and most prevalent agricultural practices in India and many other regions of the world. In these areas, wetland culture is the predominant soil management system. Rice occupies 153 m ha land throughout the world. In India, out of the 43 m ha area under rice cultivation puddled rice culture occupies 24 m ha, about 56% of the area (Anonymous, 2005; Singh, 2001). This involves ploughing the soil when wet, puddling it and keeping the area flooded for the duration of the rice crop. Wetland rice culture thus destroys soil structure and creates a poor physical condition for the following wheat crop. This soil condition can reduce wheat yield (Sur et al., 1981; Boparai et al., 1992) presumably by limiting root growth and distribution (Oussible et al., 1992). Puddled soils shrink on drying, become compact and hard and produce surface fissures of varying size and shape. Ploughing of puddled soils after rice results in the formation of large clods with high breaking strength (Sharma and Bhagat, 1993). Creating an appropriate seedbed requires a large amount of energy and time. For regeneration and maintenance of soil structure within this cropping system, plant residue is very important (Verma and

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Bhagat, 1992), but for various reasons, the amount of residue being returned to the soil is not adequate. Incorporation of plant residues, coupled with appropriate tillage, can increase soil organic carbon (Bhagat and Verma, 1991), or if used as mulch, the residue can modify soil temperature (Bhagat and Acharya, 1988). A 5-year field study on the rice–wheat cropping system demonstrated that applying a combination of rice straw and farmyard manure to wheat improved soil structure and plant available water content (Bhagat and Verma, 1991; Verma and Bhagat, 1992). Other studies evaluating long-term crop residue additions with various tillage treatments have shown favourable modification of soil physical properties in typical rice soils (Bhagat et al., 1994; Sharma et al., 1995). The studies also indicated that irrespective of tillage and residue addition inevitably delayed surface drying. As a consequence, in the areas of India where this cropping system has been practiced for many years, both yield and soil fertility are showing signs of stress and declining trend (Yadav et al., 1998). This is especially true where a continuous rice–wheat rotation dominates (Fujisaka et al., 1994; Singh and Singh, 1995) the cultivation practices by the farmers. In such areas yield has been decreased significantly (Yadav, 1998) and farmers have begun using higher than recommended rates of fertilizer to maintain yield to a certain level (Modgal, 1996). These are the areas where fertilizer use has already reached a high level and further increases are not likely to be profitable. It has been suggested that undue importance has been given to nutrition without adequate consideration for the soil physical environment. One way to integrate soil property information into the management decision process is to develop a soil quality index. This could be used to monitor farming system and management effects on soil quality and provide an early warning of soil degradation (Parr et al., 1992). The soil quality concept per se was introduced by Warkentin (1995) as an approach to facilitate better land use planning for multiple functions. Soil quality or the capacity of soil to function involves the interaction of many factors. Therefore, to develop sustainable agricultural practices, it is necessary to know and understand the effects of land use on soil quality (i.e. soil function). Sustainability is related to soil quality, which is defined as, "the capacity of a specific kind of soil to function, within natural or managed boundaries, to sustain plant and animal productivity, maintain or enhance air and water quality and support human health and habitation" (Karlen et al., 1997). The soil's ability to function as a component of an ecosystem may be degraded, aggraded or sustained as use-dependent properties change in response to land use and management. For example, conservation tillage practices generally result in higher amounts of soil organic matter (OM), reduced erosion, increased infiltration, increased water stable aggregates and greater microbial biomass carbon when compared to conventional tillage systems (Reeves, 1997). As far as soil quality indices are concerned, a number of proposals have been made, but no generally accepted methodology has been identified yet (Bouma, 2002; Gardi et al., 2002). One emerging concept that attempts to balance multiple soil uses, emphasizes that soil quality should not be limited to productivity but also include broader environmental effects (Karlen et al., 1997; Andrews et al., 2002). Several researchers have attempted to incorporate soil physical parameters into soil quality indices. One such parameter is the non-limiting water range (NLWR) (Letey, 1985), defined as the range of soil water content where neither water content, oxygen or mechanical resistance limits plant growth. A soil with a small NLWR would be defined as having lower quality because it requires careful management to keep the water content in the non-limiting range. Several cultural practices can change the NLWR. This includes applying organic waste to land, modifying tillage practices and crop rotations, irrigating with saline water, using cover crops or different forms of fertilizer and altering wheel-traffic patterns. The least limiting water range (LLWR) has been proposed as an index of the structural quality of soils for crop growth (da Silva et al., 1994) and is based on the concept introduced by Letey (1985). The LLWR is defined as the range in soil water content within which limitations to plant growth associated with water potential, aeration and mechanical resistance to root penetration are small. da Silva and Kay (1997a,b) have demonstrated that crops growing on soils, which have a narrow LLWR, are more vulnerable to both drought and high precipitation than those crops growing on soils, which have a wider range. Singh et al. (1992) integrated soil physical properties into a tilth index that focused on five soil physical properties—bulk density, cone index, aggregate size uniformity coefficient, organic matter and plasticity index. Smith et al. (1993) developed an approach (multiple indicator krigging procedure) that integrates an unlimited number of soil quality indicators, measured spatially, into an overall soil quality index and then used their procedure to evaluate soil quality across landscapes. This study presents the results of a 3-year field experiment that was conducted on a Vertisol in central India. A new index based on bulk density, soil penetration resistance, water stable aggregates and organic matter content was developed. The objective was to develop a new index for soil quality assessment and to test the applicability of the index to evaluate the

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