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Effect of ten years of reduced tillage and recycling of organic matter on crop yields, soil organic carbon and its fractions in Alfisols of semi arid tropics of southern India

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ABSTRACT

Reducing tillage intensity and retaining residues are important components of conservation agriculture but in small holder systems in developing countries where crop residues have alternate uses such as fodder and fuelwood, recycling or external additions of organic matter may be a possible option. Information on impacts of long term reduced tillage on soil carbon, labile organic carbon fractions and their depth distribution is scant in drylands of semi arid regions. The effect of tillage intensity (CT—conventional tillage; RT—reduced tillage and MT—minimum tillage) and sources of nitrogen (100% OS: 100% of recommended N through organic source; 50% OS +50%IOS: 50% N through organic source and 50% N through inorganic source and 100% IOS: 100% N through inorganic source) on crop yields, soil organic carbon and C fractions in an Alfisol was assessed at the end of a 10 year long term experiment. Finger millet yields decreased significantly with reduction in tillage intensity (29%). Among N sources, highest yields were recorded with substitution of 50% of the N through organic source. After 10 years, the soil organic carbon (SOC) in 0–20 cm soil layer with MT was 11% higher than with CT. The labile fractions of carbon, viz. particulate organic carbon (POC), microbial biomass carbon (MBC) and permanganate oxidizable carbon ($KMnO_4$-C) under MT were 47%, 16% and 43% higher, respectively, in comparison to CT in the 0–20 cm soil layer. The total carbon (TC) and total organic carbon (TOC) with MT were higher by 28% and 27% over CT and higher by 20% and 20% with 100%OS over 100% IOS. Labile carbon fractions revealed differential sensitivity and POC, MBC and $KMnO_4$-C are sensitive indicators to detect short term management effects. Reducing tillage intensity and applying various N sources enhanced SOC marginally and the C sequestration rate varied from 62 to 186 kg ha^{-1} yr^{-1}. Based on the study it can be recommended for substitution of 50% of the recommended N with organic source as it increases crop yields and soil carbon and could be a potential alternative for residue retention for crops which have fodder value. Reducing the tillage intensity can enhance the SOC in semi arid rainfed systems but lower crop yields under MT is a concern which needs to be addressed in order to make these systems acceptable to the farming community.

1. Introduction

Continuous and intensive tillage practices lead to loss of soil carbon and it has been estimated that globally 60–90 Pg of soil organic carbon (SOC) was lost during the last several decades (Lal, 1999). Adoption of traditional management practices including deep tillage and inversion combined with the removal of crop residues has resulted in SOC depletion which has exacerbated soil degradation and diminished the physical, chemical and biological properties of the soil (Lal, 2004). In the rainfed arid, semiarid, and sub humid regions of India, next to poor rain water management, depletion of nutrients caused by low SOC stock is an important cause of soil degradation resulting in poor soil physical quality, loss of favorable biology, and occurrence of multiple nutrient deficiencies resulting in low productivity (Srinivasarao et al., 2013). In order to meet the growing requirements of human and

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livestock population in the years to come, there will be greater pressure on the soils of rainfed regions of India to produce more which may aggravate degradation if remedial measures are not adopted. Improving SOC stock is, therefore, crucial to sustaining soil quality and enhancing agricultural productivity particularly from the rainfed regions (Srinivasarao et al., 2011c).

In India, Alfisols cover an area of 42 m ha, and are predominant in the states of Andhra Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu and Uttar Pradesh (Bhattacharyya et al., 2013). Finger millet and pigeonpea are important crops grown in Alfisols of peninsular India. Finger millet was grown in about 1.5 m ha during 2009 in the state of Karnataka alone and Finger millet-pigeonpea is an important rotation widely practiced in Alfisols of peninsular India under rainfed conditions. Inherently low soil fertility status, imbalanced nutrient application, depletion of SOC, lack of crop residue recycling and micronutrient deficiency are some of the nutrition related constraints which are widespread in crops grown on Alfisols. Alfisols in peninsular India are distributed in arid and semi arid regions with low and highly variable rainfall coupled with shallow depth and low water retention characteristics leading to frequent drought stress resulting in lower crop productivity and large yield gaps. Alfisols in peninsular India support a single rainy season crop (kharif or summer) with productivity levels of 0.7–0.8 Mg ha^{-1} under semiarid conditions. Low biomass application and crop residue retention, coupled with long fallow periods which extend up to 9 months in a year result in adverse environments that do not sustain SOC levels. The magnitude of decline or enhancement of SOC due to continuous cultivation depends on the balance between the loss by oxidative processes during tillage, the quantity and quality of crop residues that are returned, and the organics added to the soils (Srinivasarao et al., 2011b).

Reducing the tillage intensity and maximizing the surface cover through retention of crop residues are the essential components of conservation agriculture (FAO, 2013). Conservation agriculture (CA), considered as an alternative strategy world over to sustain and possibly to improve the agricultural production, is widely reported to reduce soil erosion, enhance infiltration, improve soil organic stocks and enhance soil quality in varied crops and environments, while reducing risks of soil degradation under rainfed conditions (Vlek and Tamene, 2010). However, development of CA systems in rainfed agriculture is at infancy in India due to several reasons. Availability of sufficient amounts of crop residues for surface retention is a major issue in rainfed ecosystems as cropping is restricted to a single season and crop residues are used as fodder for the large livestock population. The benefits associated with reducing the tillage intensity are limited in the absence of retention of crop residues (Vanlauwe et al., 2014; Sayre et al., 2006; Derpsch et al., 2014) particularly under rainfed conditions where the soil is exposed without any vegetative cover for up to 9 months a year. Small holder farmers in developing countries generally manage intensive, mixed crop-livestock systems where animals are extremely important components and contribute to food security of the household, provide for system diversification, generate cash, spread risk, provide draft power, and transportation and are important assets for investment and savings (De Hann et al., 1997).

As crop residues for the predominant rainfed crops are valued for feed particularly by the small farmers in drier environments of northern and southern Africa, West Asia and parts of South American Andes (Wall, 2010), retaining the residues on the soil surface may not be a feasible option. Some of the alternative options suggested are gradual transition to CA by initiating only a small part of the farm (about 10% every year) and gradually expanding to the whole farm (Derpsch, 2001), introducing fodder crops into the system and integrating trees into the existing arable systems (Wall, 2010), which may not be possible under Indian situation because of the small size of the holdings (<1.0 ha), single cropping season and severe competition between the annuals and the perennials for moisture resulting in substantial reduction of crop yields under rainfed conditions (Rao et al., 1991). One of the feasible alternatives could be to use the crop residues as animal fodder and utilize the manure obtained from the farm as surface cover which can also meet part of the nitrogen requirement of the crops. Integrating farm-generated organic manure with inorganic fertilizers to increase SOC, and combining crop rotation, residue management and reducing the tillage intensity appears to be the feasible strategy under rainfed conditions (Campbell and Zentner, 1993) particularly for small farmer situations where the holdings are <1.0 ha and land degradation is severe. We hypothesized that use of manure and other sources of organic matter as a substitute for retention of crop residues together with minimum tillage will have the same benefits associated with the CA systems as practiced in other parts of the world and may favorably influence the SOC content which can sustain the productivity of the system.

Intensive cropping over the years encourages oxidative losses of C due to continuous soil disturbance, while cropping results in large scale addition of C to the soil through addition of crop residues which either results in net addition or depletion of soil C stocks (Majumder et al., 2008). Cropping systems and management practices that ensure greater amounts of crop residues returned to soil are expected to cause a net build up of the SOC stock. Identifying such systems or practices is a priority for sustaining crop productivity particularly under the rainfed conditions. As accumulation of C in soil is a slow process, and perceptible changes in SOC may not be seen over short term (Bonilla et al., 2014) and in order to understand whether C is stabilized in the soil, the SOC has to be separated into soil C fractions that are more sensitive to changes in agricultural management practices (Parton and Rasmussen, 1994). While there are several studies on the changes in SOC due to integrated nutrient management (Srinivasarao et al., 2011a,b, 2012a,b; Majumder et al., 2008), relatively few studies have focused on impacts of reduced tillage on the SOC under semi arid tropical conditions.

Agricultural practices for enhancing SOC must either increase organic matter inputs to the soil, decrease decomposition of soil organic matter (SOM) and oxidation of SOC, or a combination of both (Paustian et al., 2000). Conservation tillage systems consisting of reduced tillage, retention of crop residues are reported to accumulate soil carbon in both the temperate, tropical and Mediterranean environments (West and Post, 2002; Gonzalez Sanchez et al., 2012). Crop residues left on the soil surface adds substantial carbon to the soil and reduced tillage minimizes the soil disturbance and thus slower stubble incorporation and reduces rate of mineralization of organic matter and lowers susceptibility to physical disruptive forces (Mikha and Rice, 2004). Due to the retention of stubbles and root biomass under no till systems, SOC is physically protected from microbial decomposition through formation of stable micro and macro aggregates by forming a physical barrier between the substrates and microbes (Tripathi et al., 2014). Experiments carried out on limited scale under rainfed conditions in India have concluded that grain yields were low with minimum or reduced tillage systems during the initial years and do not have major yield advantage over conventional tillage system without incorporation of residues (Sharma et al., 2009; Venkateswarlu et al., 2010). Very few long term studies are available wherein the effects of reducing the tillage intensity was studied in association with the addition or retention of the organic matter particularly under rainfed conditions in India. Keeping this in view, the present study was made with the following objectives (i). To find out the effect of reducing the tillage intensity on crop productivity and soil carbon