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Conservation agriculture effects on soil organic carbon accumulation and crop productivity under a rice–wheat cropping system in the western Indo-Gangetic Plains

Ranjan Bhattacharyya[a,*], T.K. Das[b], S. Sudhishri[c], B. Dudwal[b], A.R. Sharma[d], A. Bhatia[d], Geeta Singh[e]

[a] Centre for Environment Science and Climate Resilient Agriculture, NRL Building, ICAR-Indian Agricultural Research Institute (IARI), Pusa, New Delhi 110 012, India
[b] Division of Agronomy, ICAR-IARI, Pusa, New Delhi 110 012, India
[c] Water Technology Centre, ICAR-IARI, Pusa, New Delhi 110 012, India
[d] Director, Directorate of Weed Science Research, Jabalpur, Madhya Pradesh, India
[e] Division of Microbiology, ICAR-IARI, Pusa, New Delhi 110 012, India

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ABSTRACT

Retention of carbon (C) in arable soils has been considered as a potential mechanism to mitigate soil degradation and to sustain crop productivity. Hence, we appraised the 3-year effect of different conservation agriculture (CA) practices on grain yield, biomass productivity and soil organic C (SOC) accumulation rates under a tropical rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) and rice–wheat–green gram (mungbean in Hindi; *Vigna radiata*) cropping systems. Results indicate mean (of three years) rice grain yield under mungbean residue + direct seeded rice (DSR) followed by zero tilled wheat (ZTW) with rice residue (RR) retention and zero tilled relay summer mungbean (MBR + DSR-ZTW + RR-ZTMB) plots was similar to farmers' practice [transplanted rice (TPR)- conventionally tilled wheat (CTW)], despite TPR-CTW plots had ~18% higher rice yield than MBR + DSR-ZTW + RR-ZTMB plots in the first year. The MBR + DSR-ZTW + RR-ZTMB treated plots had about 15 and 10% higher mean wheat grain yield and mean system productivity (sum of grain yields of all crops) than TPR-CTW plots, respectively. The plots under DSR + brown manuring (BM)-ZTW + RR plots had comparable mean rice and wheat yields to MBR + DSR- ZTW + RR-ZTMB plots. Harvestable aboveground biomass productivity of MBR + DSR-ZTW + RR-ZTMB treated plots was ~2.89 Mg ha^{-1} yr^{-1} higher than TPR-CTW. Total estimated C input (~12.1 Mg C ha^{-1} in three years) under MBR + DSR-ZTW + RR-ZTMB treated plots was ~117 and 127% higher than DSR-ZTW and TPR-CTW treatments, respectively. All CA plots had significantly higher gain (over initial value) in total SOC than that in TPR-CTW and TPR-ZTW treatments in the 0–15 cm layer and the gain in total SOC in the plots under MBR + DSR- ZTW + RR-ZTMB was significantly higher than all CA plots, despite having similar total SOC stocks. Again, plots under MBR + DSR-ZTW + RR-ZTMB had ~24% larger labile C pools than that of TPR-CTW (3.1 g kg^{-1}) treated plots in the topsoil. Soil bulk density under MBR + DSR- ZTW + RR-ZTMB and DSR + BM-ZTW + RR treated plots significantly decreased in the 5–15 cm layer compared to TPR-CTW plots. Thus, the MBR + DSR-ZTW + RR-ZTMB treatment (a novel CA practice), has considerable potential to retain C in surface soil, decrease soil compaction and increase system (rice–wheat–green gram) productivity and hence its adoption is recommended.

1. Introduction

During the post-green revolution era, the issues of conservation have assumed greater importance in view of widespread resource degradation problems and the need to reduce production costs. Conservation agriculture (CA) is one concept for resource conservation and mitigation of adverse climatic impacts that has higher

Abbreviations: CA, conservation agriculture; SOC, soil organic C; SOM, soil organic matter; ZT, zero tillage; CT, conventional tillage; RR, rice residue; BM, brown manuring; TPR, transplanted rice; DSR, direct seeded rice; MBR, mungbean (green gram) residue; ZTW, zero tilled wheat; ZTMB, zero tilled mungbean; ABP, aboveground biomass productivity; SMD, soil moisture deficit.

* Corresponding author.
E-mail address: ranjan_vpkas@yahoo.com (R. Bhattacharyya).

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profitability (Das et al., 2014). This technology involves minimum soil disturbance, providing a soil cover through crop residues or other cover crops and crop rotations for achieving higher productivity (Mishra et al., 2015; Bhattacharyya et al., 2015). Despite efforts by many national and international agencies in collaboration with state extension departments, area under CA is not expanding and one of the reasons is non-suitability of the location specific appropriate technologies (Bhattacharyya et al., 2015). The maximum gain of CA can be realized only if the cropping systems are taken into consideration.

Rice (*Oryza sativa*)–wheat (*Triticum aestivum*) production systems occupy ∼24 million ha (M ha) of cultivated land in the Asian subtropics, and the Indo-Gangetic Plains (IGP) occupies ∼10.5 M ha out of that 24 M ha (Ladha et al., 2009). Direct seeding is a conservation tillage method which aims to establish agricultural and environmental sustainability. It is being increasingly adopted worldwide (∼90 M ha) (Derpsch, 2001, 2003), especially in tropical and semi-arid tropical agro-ecosystems. Retention of crop residues before rice transplanting is an efficient management approach for increased productivity, nutrient use efficiency and sustainability without affecting soil quality. In northern India, some farmers, after wheat harvest in April, grow short-duration green-manuring crops to improve soil health. Green manure *Sesbania* and green gram have been used to improve N supply in rice–wheat production systems. Retention of green manures in rice helps to improve soil nutrient status and promotes soil microbial activity (Singh et al., 2011). These alternative practices are known to exert positive effects on chemical, physical and biological soil properties (Bhattacharyya et al., 2006, 2013a, 2014).

Farmers in this region mainly adopt transplanted rice because puddling has many advantages, including less weed density, better soil chemical environment and nutrient availability in these alkaline soils due to the creation of anaerobic conditions. However, due to deterioration of soil physical health, direct seeded rice (DSR) – zero tilled wheat (ZTW) along with residue incorporation/retention could be an alternative technology for better soil health and system productivity. Then again, due to weed management and wheat residue management problems, along with reduced crop productivity in the initial years, farmers do not prefer zero-tilled DSR. Hence, a tilled DSR-ZTW could be a viable technology in the region that avoids wet cultivation, manages weeds and uses less water compared with wet cultivation and advocates a tillage reduction in the cropping system by >50% (no tillage in wheat and less intensive tillage for rice compared with conventionally tilled wheat and intensive tillage operations for wet cultivation in rice). Although, studies in the past compared conventional transplanted rice-conventionally tilled wheat (TPR-CTW) versus zero tilled DSR-ZTW (Kumari et al., 2011), limited information is available on the relative performances of different CA practices like tilled DSR-ZTW with or without rice residues, tilled DSR-ZTW with or without brown manuring (BM) and tilled DSR-ZTW- zero-tilled mungbean (ZTMB) with or without rice residue retention on the net primary productivity and soil C pools compared with TPR-CTW.

Conservation agriculture practices are encouraged for reasons of soil and water conservation, amelioration of soil compaction and C sequestration (Allmaras and Dowdy, 1985). The post-harvest rice residue-C is normally eliminated by open-field burning in several countries including India (Kausar et al., 2010). For soil sustainability of this cropping system, plant residue recycling is very important. Another advantage of CA is that, it involves the use of minimum or zero tillage along with crop residue retention is this addresses soil physical degradation problems by reducing sub-surface compaction (Sayre and Hobbs, 2004). Residue retention or incorporation generally increases soil C content worldwide (Das et al., 2013). However, the rate of added C retention in the plots under different levels of residue retention/incorporation in a sub-tropical agro-ecosystem is limited after varied management practices as said above. Labile C pools play a greater role than recalcitrant pools in the short-term turnover of C, and as such influence the functioning of soils, and are considered suitable indicators of soil quality (Gregorich et al., 1994; Bhattacharyya et al., 2010). While the literature indicates that the labile C pools are more sensitive than total soil organic C (SOC) to management effects, comparisons among the different C fractions under above-said CA practices (especially with brown manuring) have been scant.

Thus, the objectives were: (i) to determine the impacts of novel CA practices on grain yield, aboveground biomass productivity (ABP) and total SOC accumulation in the 0–15 cm soil layer after three years of an irrigated rice–wheat cropping system and (ii) to evaluate labile and recalcitrant C pools in the 0–5 and 5–15 cm layers as affected by different CA practices in a sandy clay loam soil of the western IGP. We hypothesized that: (i) plots under tilled DSR-ZTW + RR would have larger C stock and labile C pools compared with TPR-CTW plots (farmers' practice) and (ii) inclusion of zero tilled summer mungbean (green gram) and its residue retention with DSR-ZTW + RR (MBR + DSR-ZTW + RR-ZTMB treatment) or brown manuring under DSR-ZTW + RR plots (BM + DSR-ZTW + RR) would perform better than DSR-ZTW + RR plots.

2. Materials and methods

2.1. Experimental site

The experimental field was laser-levelled during September 2009. A uniformity trial on wheat was undertaken during winter 2009–2010 to ensure uniform soil fertility in the entire field. The experiment was carried out at the Indian Agricultural Research Institute (IARI), New Delhi (28°35′N, 77°12′E, altitude 228 m above mean sea level). New Delhi has a sub-tropical and semi-arid climate with hot and dry summers and cold winters. May and June are the hottest months with mean daily maximum temperature varying from 40 to 46 °C, while January is the coldest month with mean daily minimum temperature ranging from 6 to 8 °C. The mean (of last 40 years) annual rainfall is 710 mm, of which 80% is received during southwest monsoon from July to September and the rest is received through 'Western disturbances' from December to February. The mean wind velocity varies from 3.5 km h^{-1} during October to 4.3 km h^{-1} in April. Pan evaporation varies between 3.5 to 13.5 mm d^{-1} and reference evapotranspiration from 9 to 15 mm d^{-1}. Mean monthly values of meteorological parameters recorded at the IARI meteorological observatory adjoining to the experimental site during the experimental period (July 2010–June 2013) are presented in Fig. 1.

Ten soil samples (0–15 cm depth) were taken randomly during June 2010 from the experimental field and analyzed individually for available macro- and micro-nutrients. Soil (Typic Haplaquept) was sandy clay loam, with pH 8.3, Walkley–Black C 6.0 g kg^{-1} (Walkley and Black, 1934), total SOC 7.5 g kg^{-1} and electrical conductivity of the saturated extract 0.69 dS m^{-1}. The soil was low in $KMnO_4$-oxidizable N (75.5 g kg^{-1}), medium in Olsen's P (10.68 g kg^{-1}) and NH_4OAc-extracable K (125.63 g kg^{-1}). The initial soil (0–15 cm) bulk density was 1.50 Mg m^{-3}. The experiment was initiated from the rainy-season 2010.

2.2. Treatments and practices adopted and fertilizer management during the field study (2010–2013)

Eight treatments (Table 1) were laid out in a randomized complete block design with three replications. The treatments where rice residues were retained and ZT was practiced with a cover crop might be considered as CA practices. The individual plot size