Europ. J. Agronomy 51 (2013) 34–42

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Impacts of conservation agriculture on total soil organic carbon retention potential under an irrigated agro-ecosystem of the western Indo-Gangetic Plains

T.K. Das, Ranjan Bhattacharyya*, A.R. Sharma[1], S. Das, A.A. Saad, H. Pathak

Indian Agricultural Research Institute, Pusa, New Delhi 110 012, India

ARTICLE INFO

Article history:
Received 4 May 2013
Received in revised form 2 July 2013
Accepted 3 July 2013

Keywords:
Carbon addition and storage
Conventional and zero tillage
Bed planting
Residue management
Wheat based cropping
Indo-Gangetic Plains

ABSTRACT

Sequestration of C in arable soils has been considered as a potential mechanism to mitigate the elevated levels of atmospheric greenhouse gases. We evaluated impacts of conservation agriculture on change in total soil organic C (SOC) and relationship between C addition and storage in a sandy loam soil of the Indo-Gangetic Plains. Cotton (*Gossypium hirsutum* L.) and wheat (*Triticum aestivum* L.) crops were grown during the first three years (2008–2011) and in the last year, maize (*Zea mays* L.), wheat and green gram (*Vigna radiate* L.) were cultivated. Results indicate the plots under zero tillage with bed planting (ZT-B) and zero tillage with flat planting (ZT-F) had nearly 28 and 26% higher total SOC stock compared with conventional tillage and bed planting (CT-B) (~5.5 Mg ha^{-1}) in the 0–5 cm soil layer. Plots under ZT-B and ZT-F contained higher total SOC stocks in the 0–5 and 5–15 cm soil layers than CT-B plots. Although there were significant variations in total SOC stocks in the surface layers, SOC stocks were similar under all treatments in the 0–30 cm soil layer. Residue management had no impact on SOC stocks in all layers, despite plots under cotton/maize + wheat residue (C/M+ W RES) contained ~13% higher total SOC concentration than no residue treated plots (N RES; ~7.6 g kg^{-1}) in the 0–5 cm layer. Hence, tillage and residue management interaction effects were not significant. Although CT-B and ZT-F had similar maize aboveground biomass yields, CT-F treated plots yielded 16% less maize biomass than CT-B plots. However, both wheat and green gram (2012) yields were not affected by tillage. Plots under C/M + W RES had ~17, 13, 13 and 32% higher mean cotton, maize, wheat and green gram aboveground biomass yields than N RES plots, yielding ~16% higher estimated root (and rhizodeposition) C input in the 0–30 cm soil layer than N RES plots. About 9.3% of the gross C input contributed towards the increase in SOC content under the residue treated plots. However, ~7.6 and 10.2% of the gross C input contributed towards the increase in SOC content under CT and ZT, respectively. Thus, both ZT and partial or full residue retention is recommended for higher soil C retention and sustained crop productivity.

1. Introduction

Storing C in soil of the arable ecosystems has the potential to offset a portion of the future atmospheric increases in CO_2. Resource conservation issues have drawn the attention of scientists to devise innovative tillage and crop establishment techniques for higher productivity. Conservation technologies involve minimum soil disturbance, providing a soil cover through crop residues or other cover crops, and crop rotations for achieving higher productivity and minimize adverse environmental impacts. In the conventional systems involving intensive tillage, there is a gradual decline in soil organic matter through accelerated oxidation and burning of crop residues (that is a common practice in the upper Indo-Gangetic Plains) causing pollution, greenhouse gases emission, and loss of valuable plant nutrients. Aggressive seed-bed preparation leads to declining soil fertility and biodiversity. When the crop residues are retained on soil surface in combination with no-tillage, it initiates processes that lead to improved soil quality and overall resource enhancement. Therefore, conservation technologies may lead to sustainable improvements in the efficient use of water and nutrients by improving nutrient balances and availability, infiltration and retention by soils reducing water losses due to evaporation, and improving the quality and availability of ground and surface water (Sharma et al., 2005).

Cotton is an important fibre crop grown throughout India under both rainfed and irrigated conditions on an area of 9.5 million hectares (M ha). Wheat is the second most important cereal crop after rice, grown on 26 M ha and meets the nutritional requirement

* Corresponding author. Tel.: +91 01125842454; fax: +91 01125842454.
E-mail address: ranjan_vpkas@yahoo.com (R. Bhattacharyya).
[1] Director, Directorate of Weed Science Research, Maharajpur, Jabalpur 482004, MP, India.

1161-0301/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.eja.2013.07.003

of majority of the people. Both these crops contribute significantly towards the livelihood of large number of people engaged in their cultivation, trade, processing etc. Development of short-duration early-maturing varieties of cotton and expansion of irrigation facilities have led to cultivation of these crops in sequence in the north-western parts of India. Accordingly, cotton–wheat cropping system occupies an important place in the agricultural economy of this region, covering 1.7 M ha in the states of Punjab, Haryana and Rajasthan (Monga et al., 2009).

However, production of cotton showed a declining trend, with wide fluctuations in area and productivity (Mayee et al., 2008). The major constraints encountered were: inadequate crop stand due to poor emergence owing to crust formation after sowing, seedling burning due to high temperature at emergence, alkalinity and salinity problems, and increased incidence of pests e.g. boll worms, white fly and jassid, and diseases e.g. wilt, root rot and black arm (Brar et al., 1998). Likewise in wheat, delay in sowing due to late harvest of cotton resulted in reduction of yield due to prevalence of hot winds during March–April (Lobell et al., 2012). These factors lead to consideration of other cropping systems like maize–wheat–green gram system that has the provision of growing a legume for better profitability and sustained productivity.

Studies on no-tillage and bed planting technologies have recently been conducted in wheat in the rice–wheat cropping system in the north-western plain zone of India. There is already a greater emphasis on crop diversification due to growing concerns about the un-sustainability of the rice–wheat system in this region. In the north-western India, especially in Punjab, Haryana and Rajasthan, more than 95% area of rice as well as wheat is under irrigation. All these conditions call for efficient soil management to achieve sustainable production that can minimize C loss and retain more C in soil layers. Published results from field experiments have shown increases in soil C content usually result under zero-tilled soils in comparison with tilled soils (West and Post, 2002; Alvarez, 2005; Bhattacharyya et al., 2008, 2009a, 2012a,b). Bed planting under conventional tillage (CT) and zero tillage (ZT) generally saves irrigation water (Gathala et al., 2011), labour consumption without sacrificing crop productivity (Hobbs and Gupta, 2000; Gupta et al., 2003; Ladha et al., 2009). Residue retention generally increases soil carbon content worldwide (Saharawat et al., 2010). However, the rate of added C retention in the plots under different levels of residue retention in a sub-tropical agro-ecosystem is probably unknown after both ZT and CT.

Keeping this in view, the present study was conducted to find out the effect of different tillage and crop establishment techniques on the performance of wheat based cropping systems, where cotton–wheat was tried for the initial three years and then the maize–wheat–green gram for the last year. The specific objectives were: (i) to determine the impacts of conservation agriculture (CA) on biomass production and soil C retention in the 0–30 cm soil layer and (ii) to evaluate a relationship between added C and retained C after four years of residue management in a sandy loam soil of the western IGP. We hypothesized that residue retention would result in larger biomass production and retain more C in the soil compared with no residue treated plots and the plots under ZT (with or without bed planting) would have higher total SOC than CT plots.

2. Materials and methods

2.1. Site

An experiment on wheat based cropping system was conducted during 2008–2012 at the research farm of the Indian Agricultural Research Institute (IARI), New Delhi. The soil (0–15 cm) was sandy loam in texture with bulk density of 1.57 Mg m^3, field capacity 17.48% (w/w) and infiltration rate 1.26 cm h^{-1}. It had 5.5 g kg^{-1} Walkley–Black C (WBC), 168.5 kg $KMnO_4$ oxidizable N ha^{-1}, 11.8 kg 0.5 N $NaHCO_3$ extractable P ha^{-1}, 235.1 kg 1 N NH_4OAc exchangeable K ha^{-1}, 7.5 pH and 0.31 dS m^{-1} EC at the start of the experiment. Bulk density and WBC of the 15–30 cm soil layer were 1.60 Mg m^{-3} and 5.1 g kg^{-1}, respectively. The plots were under maize–wheat system with recommended mineral fertilization for both crops before commencement of this experiment.

2.2. Experimental details

During 2008–2011, the experiment was conducted on a cotton–wheat cropping system. However, in order to attain higher crop productivity and to include one legume in the crop rotation, the cropping system was changed to maize–wheat–green gram since July 2011. Four tillage and crop establishment practices, viz. conventional tillage – flat sowing (CT-F), conventional tillage – raised-bed sowing (CT-B), zero tillage – flat sowing (ZT-F) and zero tillage – raised-bed sowing (ZT-B) and four residue management practices, viz. no residue (NRES), cotton or maize residue (C/MRES), wheat residue (WRES), cotton or maize + wheat residue (C/M + WRES). The experiment was laid out in a split-plot design, keeping tillage and crop establishment practices in main plot (27.0 m × 2.8 m) and residue management practices in subplot (6.0 m × 2.8 m) with three replications. Thus, in total, there were 12 main plots and 48 sub-plots.

2.3. Tillage, residue management and sowing

In the main plots, conventional tillage involved one ploughing with a tractor drawn disc plough, followed by harrowing and planking, while in zero tillage no ploughing was done. Fresh raised-beds (about 40 cm width) were prepared for every crop (except the green gram crop) in the plots under conventional tillage-bed planting, while the beds were reshaped once in a year in the plots under ZT-B with a bed planter. Residues of the respective crops were retained on surface at harvest under zero tillage, while these were incorporated under conventional tillage. Cotton residue involved the leaves and tender twigs along with boll husk, while wheat residue was retained as such after harvesting the crop with a combine harvester.

In order to ensure good germination, a pre-sowing irrigation was given to the field prior to sowing of cotton. The sowing of cotton (cultivar MRC 7017 ('Nikki')) was done during May 2008, 2009 and 2010 by dibbling method with row spacing of 70 cm and plant to plant spacing of 60 cm in all plots. The seeds maize (at 20 kg ha^{-1}) were also sown in rows 70 cm apart in all plots in late June 2011. The wheat crop (cultivar HD 2932) was sown at a row spacing of 18 cm in the plots under CT-F and ZT-F treatments using a multi-crop planter, while a bed-planter was used to establish three rows of the wheat crop on top of the raised beds (35 cm). The seed rate of wheat used for sowing on beds and flats was 100 kg ha^{-1}. Green gram was sown with a row spacing of 20 cm and 20 kg ha^{-1} seed rate. All crops were irrigated as and when hairline cracks appear.

2.4. Crop management

A common dose of 100 kg N + 60 kg P_2O_5 + 40 kg K_2O ha^{-1} was applied to cotton, of which, P and K were applied as basal along with 50% N, and the remaining N was given after one month of growth. For wheat also, a common dose of 120 kg N + 60 kg P_2O_5 + 40 kg K_2O ha^{-1} was applied, of which P and K were applied as basal along with 50% N through seed-cum-fertilizer drill or bed planter, while the remaining N was top-dressed in two equal splits after first and second irrigation. Herbicide gylphosate was sprayed at 0.5 kg ha^{-1} in the zero-till plots about a week before sowing