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TOTAL CARBON STOCK IN AGRICULTURAL SYSTEM HAVING CROP ROTATION IN TARAI REGION OF NORTHERN INDIA

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Abstract: Soil organic carbon pools are important in maintaining soil productivity and influencing the CO_2 loading into the atmosphere. Agricultural soils can mitigate the problem of carbon concentration increase in atmosphere if proper management practices are involved. In the present study, total carbon stock in crops and soil was analyzed for two years along with crop rotation practice to observe its impact on the carbon pool. For that two agricultural fields C_{12} and D_7 were incorporated with different crop rotations for two years and on the basis of this SOC, Total Carbon, soil respiration and carbon stock were measured. In the end of the study C_{12} showed higher biomass carbon stock (2.61 t ha^{-1}) as compared to D_7 (1.98 t ha^{-1}) and also higher total carbon stock (plant+soil) (40.09 t ha^{-1}) as compared to D_7 (38.30 t ha^{-1}). Results prove that agriculture can not only be the source but also an effective sink if it is properly managed with different crop rotation practices and also with no-till practice.
Keywords: Biomass; Carbon concentration; Carbon stock; Crop rotation; Soil organic carbon
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INTRODUCTION

Currently, biotic carbon sequestration is being considered a workable option for mitigating CO_2 emission to the atmosphere. Although emitted carbon from agricultural soil imparts addition to the atmospheric CO_2 (Kimble *et al*., 2002), but if proper management practices are involved then this trend can be changed up to some extent (Lal *et al*., 1998). Agricultural activities can influence the changes in soil organic carbon (SOC) both in the short and the long terms. Soil C sequestration in agricultural ecosystems can prove to be a near-term option to mitigate the enhanced level of CO_2 concentration in the atmosphere (Johnson, 1995). Different management practices that help to reduce carbon loss from agricultural soils are reduced tillage intensity, and those that enhance inputs of crop residues e.g. crop rotation, winter cover crops, and water management etc. (Lal *et al*., 1998; Paustian *et al*., 2000; West and Post, 2002; Lal, 2004; Post *et al*., 2004). Carbon sequestration in agricultural soils is also mentioned in Article 3.4 of the Kyoto Protocol. Carbon sequestration is considered as one of the important strategies for sink enhancement under Kyoto protocol. Agricultural systems representing a large portion of terrestrial ecosystems, if intensively managed, can provide an opportunity to alleviate atmospheric CO_2 in semi-permanent soil C pools. Different types of crop rotations can change soil habitat, and can stimulate biodiversity of soil microorganisms and their activity (Follett, 2001).

Agricultural soils contain planet's largest reservoirs of carbon approximately twice the amount that is stored in all terrestrial plants and hold potential for expanded carbon sequestration (Marland *et al*., 2007). According to literature studies, organic agriculture having the best management practices emits less greenhouse gases as compared to conventional agriculture, and the carbon sequestration from increasing soil organic matter leads to a net reduction in greenhouse gases (Drinkwater *et al.*, 1998; Mäder *et al.*, 2002; Pimentel, 2005; Reganold *et al.*, 2001). Soil organic carbon (SOC) level at a point of time reflects the balance between additions of organic carbon from different sources and its losses through different pathways (Swarup et al. 2000). The SOC stock is comprised of labile or active pool, and stable, passive pools with changeable residence time (Chan *et al*., 2001; Mandal, 2005; Mandal *et al*., 2007).

In agricultural ecosystems crop cover is generally removed every year, so carbon sequestration means an increased carbon content of the soil (Paustian *et al*., 1998; Foereid *et al*., 2004). Cropping practices often result to reduction in SOC content in most cases (Christensen and Johnston, 1997; Paustian *et al*., 1998; Foereid *et al*., 2004), but farming practices with proper management may greatly influence soil carbon storage (Lal and Kimble, 1997; Christensen and Johnston, 1997; Foereid *et al*., 2004). These land management practices that enhance soil C storage are reducing tillage intensity and frequency, eliminating tillage, changing crop rotations, using winter cover crops, eliminating summer fallow, improving fertilizer management, adjusting irrigation methods, implementing buffer or conservation strips, and changing grazing regimes (Lal *et al*., 1999; Eve *et al*., 2002). By using statistical links between agricultural land-management practices and changes in soil organic carbon, Smith *et al*. (2000) estimated a fact that agriculture has considerable potential for carbon dioxide mitigation.

It is already documented by IPCC, 2001 that agricultural ecosystems hold large reserves of C which is mostly in the form of soil organic matter. The importance of crop rotations for increasing carbon stock at the field scale has been reported from several field experiments under different climatic conditions (Persson *et al*., 2008; Soon *et al*., 2007; Campbell *et al*., 2007; Meyer-Aurich *et al*., 2006; Yang *et al.*, 2004; Yang and Kay, 2001). There is also some evidence that carbon sequestration is related to soil type or soil texture. McConkey *et al*., (2003) observed that soil organic matter depends on the clay content in the soil.

Agriculture areas in many regions of the world have lost soil carbon (C) due to intense cultivation, deforestation, and soil erosion (Smith, 2004). However, with ability of soils to store atmospheric CO_2 in the form of organic matter, agricultural lands have been viewed as a way to mitigate greenhouse gas emissions. Various studies have placed a range on the technical potential or capacity for C sequestration that could occur through changes in agricultural land management and/or land use under "best case" situations that ignore economic, social, or institutional constraints. Crop rotation is generally considered as a succession of crops grown in regularly recurring succession on the same area of land. It imitates diversity of natural ecosystems more closely than intensive mono-cropping practices. Applying different type of crops in the area can increase the level of soil organic matter. Nonetheless, efficacy of crop rotating depends on the type of crops and crop rotation times. It has been documented earlier that crop rotations have a direct influence on the components of soil fertility *viz*. nitrogen and organic matter content and soil aggregates. Legumes have universally been recognized as fertility building agents for rotations. Legumes, if included in the rotation, can supplement the soil with fixed atmospheric nitrogen through symbiotic bacteria, *Rhizobium* spp. (Dixit, 2007).

EXPERIMENTAL

A study was established in 2009 at the Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India where two fields were chosen for carbon stock study, those were C_{12} and D_7. The total area chosen was 4.0 ha (2.0 ha each field). Each field was having crop rotations during the study. Crops grown in both the fields were totally 6 in number. These were: Wheat (*Triticum aestivum*), Lentil (*Lens culinaris*), Pigeon Pea (*Cajanus cajan*), Maize (*Zea mays*), Black Gram (*Phaseolus mungo*), and Green Gram (*Vigna radiata*).

The climate of the study site is humid, sub-tropical with dry hot summer and cold winter. The mean daily maximum and mean daily minimum temperature varied widely in all the seasons. The mean daily maximum temperature for the first year of study (2009-10) ranged between 15.72^{0}C and 39.22^{0}C and mean daily minimum between 07.00^{0}C and 27.65^{0}C. For the second year (2010-11) the mean daily maximum temperature ranged between 16.55^{0}C and 36.52^{0}C and mean daily minimum between 05.62^{0}C and 25.43^{0}C. The approximate variation in total monthly precipitation ranged from trace amount (0.1 mm) to 140.55 mm in first year while in second year from trace (0.1 mm) to 139.50 mm. The site was normally with high relative humidity throughout the year (42-92%).

1.1 Analytical procedures

Soil organic carbon (SOC) concentration in soil was measured by the modified Walkley-Black method (Walkley and Black, 1934). The soil respiration rates were calculated by alkali absorption method using 13 cm diameter and 23 cm tall aluminum cylinders inserted 10 cm deep into the soil (Coleman *et al*., 2004). Soil total carbon was analyzed by TOC analyzer (Solid Sample Module SSM-5000A for TOC-V Series Total Organic Carbon Analyzers). For TC analysis, the sample was heated to 900°C in the presence of oxidation catalyst, and the evolved CO_2 was carried by synthetic air to the non-dispersive infrared (NDIR) gas analyzer for detection. The NDIR outputs an analog detection signal that forms a peak, and the peak area was measured by the TOC–Control V software. The calibration curves that mathematically express the relationship between peak area and TC concentration were generated by analyzing various concentrations of TC standard solutions. Potassium hydrogen pthalate (KHP) was used as chemical for making standard solutions for TC (Nelson *et al*, 1996).

Above ground biomass of different crops was estimated by using 1m×1m quadrates. All the crop plants occurring within the border of the quadrate were cut at ground level. Samples were taken to laboratory and were oven dried at 65^{0}C to a constant weight. Using fresh/dry weight ratio, the dry weight of crop biomass was estimated. For below ground biomass, root samples were collected with the help of core sampler of 50 mm diameter and 15 cm length. Samples were taken in four directions, i.e. east, west, south and north crossing each other at root collar. Along each line, samples were taken at a horizontal distance of 1, 2, 3, and 4 m from the center up to a depth of 60 cm (four cores). Thus, independent of size of each plant, four core samples were taken for each crop. Roots were hand sorted from the soil cores by mean of dry sieving and were visually inspected to remove the roots of other species. Fresh weight of all the roots was taken using digital balance. The roots and soil from core was oven dried at 65^{0}C to a constant weight. The average biomass from all core samples was then converted to biomass per crop by calculating the area occupied by the crop.

Carbon concentration in crops was determined by combustion method. Oven dried samples were grinded in willey mill. 20 g of the powdered sample was taken in silica crucible. The powder material was then combusted in muffle furnace at 600°C for 4-5 hours for ashing. Carbon was assumed to constitute 50 per cent of ash free dry mass (Gallardo and Merino, 1993). The plant carbon stock was estimated by multiplying total plant biomass (ton ha^{-1}) with carbon concentration (%). The soil carbon stock was computed by multiplying the soil organic carbon (g kg-1) with bulk density (g cm^{-}3) and depth (cm) and was expressed in ton ha^{-1} (Joao Carlos *et al*., 2001). Total carbon stock (plant carbon stock+Soil carbon stock) was obtained by summing up soil and plant carbon stocks in agricultural system. All the data collected for different experiments and field samples during the study were compiled and processed for statistical treatment. The data were analyzed for the mean and standard error. Analysis of Variance (ANOVA) was used to test the significance of difference between treatment means.

RESULTS AND DISCUSSION

Crop rotation practices increased total carbon stock in the consecutive years.

2.1 Soil respiration due to microbial activity

At the C_{12} study site soil respiration varied from 621.59 to 1335.64 mg CO_2 m^{-2} hr^{-1} during the whole study period. Minimum soil respiration was observed in the month of February 2010 and maximum value was observed in the month of August 2010 and in the month of July 2011. The temperature and soil moisture were found to be the main factors influencing soil respiration of the site. For the study site D_7, the values varied from 544.89 and 1285.35 mg CO_2 m^{-2} hr^{-1} during two years of study. The minimum value was observed in the month of February 2010 while the maximum value was observed during August 2010 and June 2011 (Fig 1). Several workers observed varying range of the soil respiration in grasslands and fallow lands (Luo *et al.,* 1996; Knappa *et al*., 1998; Luo and Zhou, 2006; Upadhyay, 2007). Raich and Schlesinger (1992) observed the annual soil respiration rates increased from 400 to 500 g C m^{-2} yr^{-1} in a year.

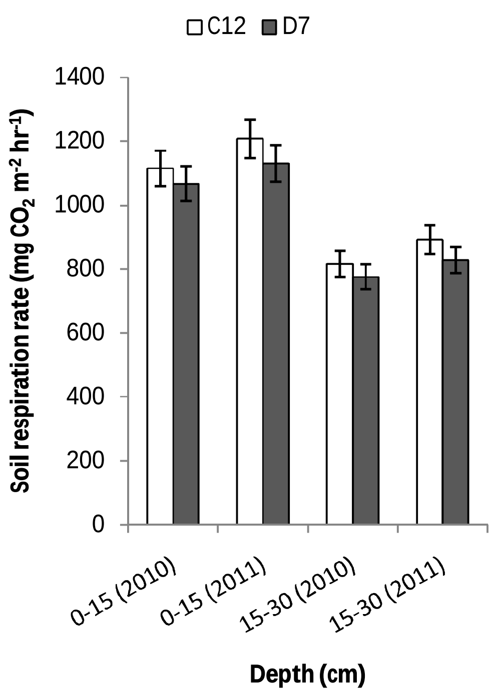

Figure 1: Soil respiration rate in the agricultural fields during the study

Figure 1 shows a significant difference in soil respiration activity in both the study sites between both depths. At the surface layer there was a noticeable increase in soil respiration in the second year in all sites and in the same way increase in available nitrogen in subsurface layer was also evident. The soil respiration strongly depends on the microbial population and carbon availability in the soil (Myrold, 1987). Overall the subsurface layer showed lesser soil respiration activity as compared to the surface layer in both fields (Shrestha *et al*, 2008). Labile carbon compounds in the litter are consumed by the microorganisms and resulted into release of CO_2 as soil respiration activity (Brady, 1990).

2.2 Soil Organic Carbon (SOC)

The minimum values for soil organic carbon content was observed in the first year of study period while the maximum in the second year in both the layers. In case of C_{12}, minimum values of SOC at 0-15 cm and 15-30 cm were observed in the month of July 2009 and these were 0.92% and 0.58% respectively. Maximum value of SOC at 0-15 cm and 15-30 cm were noticed in the month of June and April 2011 which were 1.98% and 1.15% respectively. In case of D_7, minimum value of SOC at 0-15 cm and 15-30 cm were observed in the month of July 2009 and these were 0.85% and 0.41% respectively. Maximum value of SOC (at 0-15 cm) was 1.87% in the month of June 2011 whereas at 15-30 cm, the maximum value was 1.11% in the month of January 2011. Average organic carbon content at all the study sites at each depth increased with the time elapsed however the minimum values were observed in between these due to climatic variables and different rate of decomposition of fallen litters. The decrease in the soil organic carbon with the depth may be due to relatively low microbial population in the subsurface layers and decreased decomposition activity (Chashire and Griffith, 1999; Upadhyay, 2007). According to Shrestha *et al*. (2004) the surface layer in agricultural soil also have more carbon than subsurface layer because the surface layer remains in dynamic equilibrium with biological and anthropological activities and thus is generally richer in carbon than the subsurface layers. The abundance of litter available for decomposition in the surface layer makes the release of the labile compounds in the surface layer thus making it rich in terms of soil organic carbon (Post and Kwon, 2000; Xu and Xu, 2003; Upadhyay, 2007). The periodic variation in organic carbon content of the soil is owing to the changes in the climatic variables. The higher temperature and moisture in the rainy season makes the decomposition fast resulting into increased values of carbon in comparison to winter season. Ganuza and Almendros (2003) found that temperature was one of the main factors controlling the organic carbon level in soil.

According to Lal (2003), crop rotation is among the best management practices for increasing soil carbon stock. In case of agricultural study sites (C_{12} and D_7), due to crop rotation practices and FYM (Farm Yard Manure) applications, SOC content increased in the second year of study (Su *et al*, 2006; Zotarelli *et al,* 2005; West and Post, 2002; Upadhyay, 2007). Similar results were obtained in the study done by Gaiser *et al* (2009), in which SOC content in soil was increased due to crop rotations. Apart from this, no-till in the fields during fallow periods increased carbon accumulation in the soil which is similar to the study done by Abreu *et al,* (2011) on different crop rotations.

2.2 Soil Total Carbon

For the agricultural sites of C_{12} and D_7 the minimum values for soil total carbon content were observed in the first year of study period and maximum in the second year in both the layers. In case of C_{12}, minimum value of TC at 0-15 cm was observed in the month of March 2010 and it was 1.12%, and at 15-30 cm the value was 0.68% in the month of July 2009. A maximum value of TC at 0-15 cm was observed in the month of June 2011 and it was 2.98%, and at 15-30 cm the value was 2.95% in the month of June 2010. In case of D_7, minimum value of TC at 0-15 cm was 1.08% in the month of August 2009 and at 15-30 cm, the value was 0.58% in the month of September 2009. Maximum value of TC (at 0-15 cm) was 2.63% in the month of November 2010 whereas at 15-30 cm, the maximum value was 1.98% in the month of July 2011. Overall the soil total carbon content decreased with the increasing depth of the soil at all the five study sites and in every month during the study period of two years. The value of total carbon was found higher than soil organic carbon as it covers all inorganic and organic fractions of carbon in the soil (Mikhailova *et al*, 2003; Tiessen *et al*, 1993; Nelson *et al*, 1996). According to a study done by Krishnan *et al* (2009), the total carbon content is higher than soil organic carbon due to complete oxidation of the entire carbon compound at high temperature which is not completely oxidized in Walkley and Black method.

2.3 Above and below ground biomass in the different crops at the time of harvesting

The variation in above and below ground biomass in all the crops grown was studied in the C_{12} and D_7 for two years. The variation was observed in biomass production in above and below ground parts of various crops at the time of harvesting. Above ground biomass was mainly crop biomass/straw yield (economic yield was not included) which further could incorporated into the soil and could add plant carbon into the soil. Similar study on crops was done by Sainju *et al*, 2007. In a study done by Kundu *et al*, (2007) above and belowground crop biomass was calculated to find out net carbon input from plant into the soil. In the table 1, the above and belowground biomass of all the crops is given. The boxes left blank show that the crop given was not sown in that field at that time. On the basis of the table it can be observed that in C_{12} there were three crops grown during first year of study and same were in the case of D_7. But during second year, only one crop (i.e. wheat) was grown in C_{12}. In D_7 two crops were grown. Blank boxes show no-till period. Minimum aboveground biomass was observed in Green Gram (1.71 t ha^{-1}) while minimum belowground biomass was observed in Lentil (0.06 t ha^{-1}). In the similar way, maximum aboveground biomass was observed in Maize (6.53 t ha^{-1}) whereas maximum belowground biomass was observed in the same crop as 0.90 t ha^{-1}.

Table 1: Above and below ground biomass (t ha^{-1}) in different crops at the time of harvesting

Study site with year	Type of biomass	Crop biomass (t ha^{-1})					
		Maize	Lentil	Wheat	Black gram	Pigeon Pea	Green Gram
C_{12} (Jul,09-Jul,10)	AGB	6.53	2.90	-	-	-	1.71
	BGB	0.90	0.06	-	-	-	0.09
C_{12} (Aug,10-Jul,11)	AGB	-	-	5.68	-	-	-
	BGB	-	-	0.30	-	-	-
D_7 (Jul,09-Jul,10)	AGB	-	-	5.40	-	3.82	1.82
	BGB	-	-	0.28	-	0.85	0.09
D_7 (Aug,10-Jul,11)	AGB	-	3.12	-	1.21	-	-
	BGB	-	0.08	-	0.08	-	-

2.4 C/N ratio of crops

Above and below ground carbon concentration, total nitrogen and C/N ratio for all the six crops grown in both the agricultural fields was calculated and is presented in the table 2. Carbon concentration was found minimum in case of Green Gram (Aboveground-39.20%, belowground-30.10%) whereas Black gram was having maximum aboveground carbon concentration as 45.50% and Wheat was having maximum belowground carbon concentration as 44.00%.

Table 2: Above and below ground carbon concentration (%), Total Nitrogen (%) and C/N ratio of crops

Crops	Carbon concentration		Total Nitrogen		C/N ratio	
	Above ground	Below ground	Above ground	Below ground	Above ground	Below ground
Maize	45.30	35.80	2.50	0.89	18.12	40.22
Lentil	44.10	38.70	1.80	0.80	24.50	48.37
Wheat	43.70	44.00	1.20	0.60	36.40	73.33
Black gram	45.50	40.70	1.90	0.70	23.94	58.12
Pigeon Pea	40.50	41.20	2.10	0.90	19.20	45.78
Green Gram	39.20	30.10	1.80	0.60	21.70	50.16

Above ground and below ground C/N ratio was found minimum in case of Maize (18.12% and 40.22% respectively), and maximum in case of Wheat (36.40% and 73.33% respectively). Results show that carbon concentration was found more in aboveground biomass than belowground biomass in most crops (except Wheat and Pigeon Pea) which is quite similar to the study done by Kundu *et al*, (2007). Total nitrogen content was found higher in aboveground biomass than belowground biomass. C/N ratio was found more in roots than shoots. Due to higher C/N ratio roots are comparatively hard to decompose than shoots (Kou *et al*., 2011; Shah *et al*., 2003). As reported by some researchers, a crop having high C/N ratio can supply more organic materials with a slower decomposition rate into the soil than the crop having lower C/N ratio (Eghball *et al.,* 1994; Robinson *et al.*, 1996; Bordovsky *et al*., 1999).

2.5 Above and below ground biomass carbon stock in crops

Total above and below ground biomass carbon stock of all the crops at the time of harvesting is given in the table 3. Highest aboveground biomass carbon stock was observed in Maize (2.96 t ha^{-1}) whereas lowest was observed in Black gram (0.55 t ha^{-1}). In the similar way, highest belowground biomass carbon stock was observed in Pigeon Pea (0.35 t ha^{-1}) whereas lowest was observed in Lentil (0.02 t ha^{-1}). According to Rees *et al* (2001), increasing the proportion of primary production returned to, or retained by the soil (e.g. crop residue retention and placement) enhances soil aggregation and influences carbon inputs in the soil. The fields were treated as fallow during the gap between harvesting of one crop and sowing of another crop. The fallow period is a time of high microbial activity and decomposition of organic matter with no input of crop residue (Halvorson *et al.,* 2002). Due to this, rapid decomposition of residue takes place which helps the residue to decompose into the soil and add organic matter into it. But long fallow period results into decrease in total crop biomass carbon incorporated into the soil. Therefore during second year, aboveground and belowground biomass carbon stock in crops was decreased due to minimum or no crop on fields. Therefore intensive cropping with crop rotations helps in increasing residue carbon input into the soil as compared to crop-fallow system (Sainju *et al*., 2006). The average annual total C input to soil from crops varied with above-ground yield responses of all crops under different fertilizer application (Kundu *et al*, 2007). Some studies have shown carbon input by agricultural crops into soil by tracer techniques (Kuzyakov *et al,* 2000).

Such precise calculation of carbon input in the soil is seldom, and cannot be established for each plant-soil pairs, different fertilization levels, etc. However, in many situations only a rough estimation of the annual carbon input in the soil in desirable and can be sufficient to approximate the carbon balance in the ecosystem. In present study, the main focus was on the suggestion how much crop carbon stock can be applied to the soil to enhance its carbon balance. Applicability of the suggestion is a matter of next level. Crop residue management is an important component of the carbon budget of agroecosystems. After grain harvest, crop residue (straw) can be left on the surface as mulch (conservation tillage or no-till). If returned to the soil, crop residue is a direct C input to the soil, and an indirect source of mineral N through net N mineralization as the crop residue decomposes (Sandretto, 1997; Kundu *et al*. (1997). Systems that retain crop residues also tend to increase soil C because these residues are the precursors for soil organic matter, the main store of carbon in the soil. Avoiding the burning of residues eliminates the need for pre-harvest burning (Cerri *et al*. 2004), which avoids emissions of aerosols and GHGs generated from fire. There is a strong positive relationship between the amount of C incorporated into soil, either from crop residues or from external sources such as manure, and total SOC content (Paustian *et al*., 1992; Havlin *et al*., 1990). Kundu *et al*, (2007) have also done similar study to calculate plant derived carbon inputs to the soil by estimating harvestable aboveground biomass carbon stock (or above ground biomass carbon stock) and belowground biomass carbon stock in different crop rotations in Himalayan region. The proportion of mean harvestable above-ground biomass as carbon input from different crops is different for every crop e.g. for soybean and wheat it was 29 and 24%, respectively (Kundu *et al*, 2007). But in the present study total biomass carbon stock is assumed to be as carbon input into the soil and it is just compared with the gross carbon stock of bamboo plantations. It is assumed here that if this amount of carbon is assimilated by the soil then it will enhance the level of soil carbon. Proper management practices in agriculture can make it possible.

Table 3: Above and below ground biomass carbon stock (t ha^{-1}) in different crops at the time of harvesting

Study site with year	Type of biomass	Crop biomass carbon stock (t ha^{-1})					
		Maize	Lentil	Wheat	Black gram	Pigeon Pea	Green Gram
C_{12} (Jul,09-Jul,10)	AGB	2.96	1.28	-	-	-	0.67
	BGB	0.32	0.02	-	-	-	0.03
C_{12} (Aug,10-Jul,11)	AGB	-	-	2.48	-	-	-
	BGB	-	-	0.13	-	-	-
D_7 (Jul,09-Jul,10)	AGB	-	-	2.36	-	1.55	0.71
	BGB	-	-	0.12	-	0.35	0.03
D_7 (Aug,10-Jul,11)	AGB	-	1.37	-	0.55	-	-
	BGB	-	0.03	-	0.03	-	-

2.6 Total biomass carbon stock (aboveground belowground) in both agricultural fields

Total biomass carbon stocks in the crops sown for both the years is given in the table 4 along with net carbon sequestered per year by the crops. It was observed that total biomass carbon stock was higher during first year of study than second year in both the sites. C_{12} was having maximum plant carbon stock during first year (5.28 t ha^{-1}) but it was decreased during second year (2.61 t ha^{-1}). In case of D_7, plant carbon stock during first year was found 5.12 t ha^{-1} but it was decreased during second year (1.98 t ha^{-1}). This may be because only one crop was sown during second year in this field that made the difference. The first source (root and shoot residues) of the carbon input into soils is well investigated, and the results for different ecosystems are summarized by Rodin and Basilevich (1965); Basilevich and Rodin (1971); Schlesinger (1977); Kuzyakov *et al* (2000). Leaf litter and root litter inputs play a major role in forest soil, while agricultural practices such as tillage, FYM, and fertilizer inputs and the return of crop residues determine the SOC dynamics in cultivated soils (Shrestha *et al*, 2008). Crop rotation practices along with inclusion of legumes in rotations increases carbon sequestration potential in crops (Persson *et al*., 2008; Kustermann *et al*., 2008; Soon *et al*., 2007; Meyer-Aurich *et al*., 2006).

Table 4: Total biomass carbon stock (t ha^{-1}) in both agricultural fields

Agricultural sites	Total biomass carbon stock (t ha^{-1})	
	2009-2010	2010-2011
C_{12}	5.28	2.61
D_7	5.12	1.98

2.7 Soil Organic Carbon (SOC) Stock

The soil organic carbon (SOC) stock in agricultural system at the depth of 0-15 cm and 15-30 cm is shown in table 5. The soil organic carbon stock was more in subsurface soil as compared to the surface soil. The mean values of SOC stock increased with time for all the study sites. Due to crop rotations along with no-till practice agricultural fields gained more soil carbon. Kou *et al* (2011) and Karlen *et al*., 1994) have also done similar study to observe soil carbon sequestration potential in Soybean-Maize rotation and found increase in carbon stock with each succeeding year. Mostly, SOC accumulation in farmland depends on the balance between the inputs as crop residues and manure and the exports of new and old SOM decomposition.

Table 5: Soil organic carbon (SOC) stock (t ha^{-1}) and carbon sequestration (t ha^{-1} yr^{-1}) in Bamboo plantations and agricultural system

Study sites	2010		2011		2010	2011
	0 -15 cm	15-30 cm	0-15 cm	15-30 cm	Mean	Mean
C_{12}	24.28	34.26	32.23	42.74	29.27	37.48
D_7	23.82	32.07	31.56	41.08	27.94	36.32

2.8 Total Carbon Stock (Plant + Soil)

Total carbon stock in terms of SOC stock and biomass carbon stock (above ground+below ground) for both the years is given in table 6 for all study sites. Total carbon stock in all sites was obtained by adding total plant carbon stock (biomass carbon stock) and soil carbon stock (SOC stock). In the first year total carbon stock (plant+soil) was more C_{12} (34.55 t ha^{-1}) as compared to D_7 (33.06 t ha^{-1}). Same was in the second year of study i.e. C_{12} (40.09 t ha^{-1}) was more than D_7 (38.30 t ha^{-1}).

Total carbon stock (SOC stock+Biomass carbon stock) depends on many factors like net primary productivity, biomass, litter biomass, carbon addition from plant into the soil, soil texture and many more. Agricultural system have shown better results under crop rotations practices as many studies have shown (Kundu *et al*, 2007; Kundu *et al*, 1997). The total carbon stock in agricultural system also included crop residue input into the soil and in this way it enhanced total carbon stock in agricultural system. Figure 2 represents total carbon stock sharing in crops as well as in soil. According to Rasmussen and Parton, (1994) and Rudrappa *et al*., (2005) the change in soil carbon stock is directly related to C input from crop residues and organic amendments. Enhanced C sequestration in agricultural soils not only has the potential to help reduce atmospheric CO_2 concentrations (Sperow *et al*., 2003), but also promotes the productivity and sustainability of agricultural systems (Lal, 2004).

Table 6: Total carbon stock (Plant + soil) (t ha^{-1}) and carbon sequestration (t ha^{-1} yr^{-1}) in Bamboo plantations and agricultural system

Study sites	SOC stock (t ha^{-1})		Biomass Carbon stock (t ha^{-1})		Total carbon stock (t ha^{-1})	
	2010	2011	2010	2011	2010	2011
C_{12}	29.27	37.48	5.28	2.61	34.55	40.09
D_7	27.94	36.32	5.12	1.98	33.06	38.30

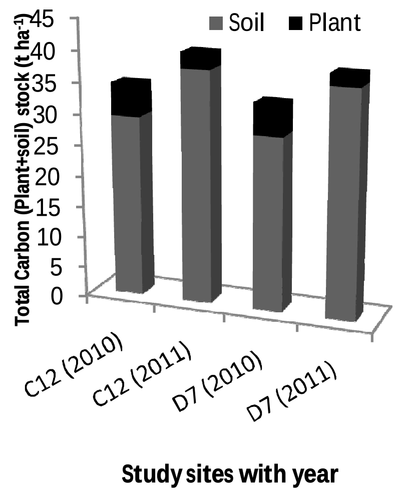

Figure 2: Total Carbon (Plant+soil) stock during the study

CONCLUSION

Agriculture may not compete with forestry or agroforestry system based on its high carbon sequestration capacity but it can enroll itself significantly in this field if some better management practices can be involved. If the straw part of the crops gets fully incorporated into the soil as mulch, it can significantly contribute to the carbon stock of the system. Present study has added knowledge base in this field significantly. The study also concluded that by some effective management practices like crop rotation, no-till, and straw incorporation into the soil, carbon sequestration capacity of agriculture is positively-affected. Soil C sequestration is also important at the farm level to build soil fertility, protecting soil from compaction, and nurture soil biodiversity. In addition to its vital role of mitigating greenhouse gas emissions, soil C sequestration provides many other significant off-farm benefits to society called as ecosystem services. These benefits include the protection of streams, lakes, and rivers from sediment, nutrient, and pathogen runoff from agricultural fields, as well as enhanced wildlife habitat. A full-system cost-to-benefit ratio of soil C sequestration from various conservation agricultural practices has not been adequately addressed, but is needed to fully appreciate this important pathway. Conservation agricultural systems promote soil C sequestration by tipping the balance in favor of C inputs relative to C outputs. Carbon sequestration can be achieved by maximizing C inputs and minimizing C outputs.

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