**Ecosystem Carbon Sustainability in Dry Land Of Punjab, Pakistan**

Asma Hassan\*1, Ratten Lal2 and Shahzada Sohail Ijaz3

*1PMAS-Arid Agriculture University. Rawalpindi, Pakistan. Asma Hassan is a visiting scholar at C-MASC, OSU, from 1st August 2013 to 31 January 2014. Telephone Number 321-5147673,*

*E mail address,* *asma\_hasan83@yahoo.com**.Or Hassan.194@ osu.edu. Postal address PMAS-Arid Agriculture University, Rawalpindi, Department of Soil Science & SWC*

*2The Ohio State University, Carbon Management and Sequestration Center (C-MASC,210 Kottman Hall, 2021, Coffey Rd, Columbus, OHIO 43235*

*3 PMAS-Arid Agriculture University. Rawalpindi, Pakistan.*

**ABSTRACT**

Efficient use of carbon (C) is principle goals of achieving agricultural and environmental sustain ability. Thus, this study was conducted in a dry land agro ecosystem in Punjab, Pakistan to compare the C-equivalence (Ceq) of inputs and outputs and theC sustainability index$ (Cs)$for different cropping sequences. Five cropping sequences were; fallow–wheat (*Triticum aestivum*) (FW) (control), mungbean (*Vigna radiata*)–wheat (MW), sorghum (*Sorghum bicolor*)–wheat (SW) green manure–wheat (GW) and mungbean-chickpea (*Cicera rietinum*) (MC).Three tillage systems included moldboard plough(MP), tine cultivator (TC) and minimum tillage (MT).The primary data collected were crop yield and the above ground biomass. Secondary data were collected to calculate C equivalence (Ceq) of inputs and outputs and to compute the carbon sustainability index (Cs). The Ceq of outputs differed among tillage treatments, and were: 135kg Ceq ha-1, 112kg Ceq ha-1 and 80.47 kg Ceq ha-1 for MP, TC and MT, respectively. On the basis mean of two years, Ceq the highest grain Ceq was measured under MP and under SW in winter (1040 kg Ceq ha-1). The maximum Ceq biomass was estimated in winter with MC (2867 kg Ceq ha-1) in summer. However, the highest root Ceq under MT was calculated in winter with MW (9500 kg Ceq ha-1). Under MT, the maximum Cs was obtained with MC for both year in summer (77 and 130). However, in winter of the second year, the highest Cs was estimated for FW (82). These results showed that the efficient use of fertilizers, herbicides, farm machinery and return of residues in the field under MT with legume based cropping system could be the best options to enhance the C sustainability index in dry lands.

***Key Words*:** Carbon use efficiency, Sustainability index, C-equivalence inputs, C-equivalence outputs, Punjab, Pakistan

Corresponding author E mail adress: asma\_hasan83@yahoo.com

1. **Introduction**

Global C emission and use efficiency have engrossed the international concern about environmental quality, global warming and sustainability of agricultural ecosystems (Kimble *et al*., 2001). Therefore, the efficient utilization of C with recommended management practices (RMPs) is a use full tool in mitigating climate change and advancing agricultural sustainability (IPCC, 2000 & Lal, 2004). Anthropogenic activities increase in emissions of greenhouse gases (GHGs) by 70% between 1970 and 2004, and these are estimated to increase further by 25% to 95% by 2030 (Rose & Mc Carl, 2008). Soils respond as source or sink of C to direct and indirect environmental anthropogenic activities. Evaluating soil and ecosystem C budgets are important to determine whether soil act as source or sink of C under different management practices. In diverse egro-ecological conditions, different tillage and crop sequences act differently on carbon sustainability index. However, in dry land reigns mostly minimum tillage with optimum crop residues and crop sequence decrease in rate of minerlization increase C storage and C sustainability index (Upendra, 2008). Estimates o f C emissions in kg Ceq ha-1 are 2–20 for machinery use, 1–1.4 for spraying chemicals 2–4 for drilling or seeding and 6–12 for combine harvesting. Similarly, estimates of C emissions (kg Ceq ha-1) for different fertilizer nutrients are 0.9–1.8 for N, 0.1–0.3 for P2O5, and 0.1–0.2 for K20. An estimate of C emission by herbicides is 5-6kg Ceq kg-1(Lal, 2004).The atmospheric concentration of CO2 reached 400 ppm in May 2013 (Carrington, 2013). Furthermore, CO2 concentration has been increasing at a faster rate than the average over the past 10-years probably because of decrease in natural C sinks (Canadell *et al*., 2007).Carbon use efficiency is computed by assessing C-based inputs and outputs used in farm operations determining the quantity of soil and efficiency of agro ecosystems (Lal, 2004). West and Marland. (2004) observed that C-based inputs include estimates of C emissions from primary fuels, electricity, fertilizers, lime, pesticides, irrigation, seed production, and tillage practices. Similarly, C-based outputs include estimates of grain yield, straw yield, and root biomass (Dubey & Lal 2009). Thus, changes in agricultural practices can also cause changes in C use efficiency (Paustian *et al*., 2000; West and Marland, 2002). For example, CO2 efflux from soil changes with change in tillage management (Aslam *et al*., 2000), Minimum tillage (MT) systems reduce CO2 emissions from farm field operations(Malhi & Lemke, 2007).In addition C emissions are directly related to fertilizer use (Choudrie *et al*., 2008), and to specific farming activities during crop production (Adler *et al.* 2007; St Clair *et al*.(2008)

Sustainable practices are those which minimize the C-based inputs maximize outputs, increase ecosystem services, and to improve the carbon use efficiency (Lal, 2004).Gill *et al.* (2002) suggested that adaptation of conservation tillage with reduce frequency of summer fallowing with new crop types in the rotation such as pulses and oilseeds (especially in dry lands) may offer opportunities to growers to improve the overall C use efficiency of production systems. The relationship between farm size and C use efficiency can differ depending on the degree of mechanization and the climatic environments. The level of mechanization, amount of arable land and type of crop are among important factors on which C use in the agriculture depends (Adi, 2004). Increasing the flow of C into soils may be even more challenging because of the growing competition for returning plant residues to soil (Gupta, 2014). The principal goal of organic farming and integrated farm management systems (IFMS) is to decrease the C losses from ecosystem which certainly have beneficial effect on the biodiversity within and around arable fields (Squire *et al*., 2000, Robinson, & Marshall *et al*., 2003). Also there is an increasing emphasis on the need to de decarbonize the global economy ([Newell, 2010](http://www.sciencedirect.com/science/article/pii/S1462901113001287#bib0190)), and to remove and sequester C in similar amounts as is produced through anthropogenic activities([Bridge, 2011](http://www.sciencedirect.com/science/article/pii/S1462901113001287#bib0045), [Bumpus & Liverman, 2010](http://www.sciencedirect.com/science/article/pii/S1462901113001287#bib0055), [Lovell & Liverman, 2010](http://www.sciencedirect.com/science/article/pii/S1462901113001287#bib0130)). Emission of CO2-C from land use, fossil fuel and cement production was 9.7Pg C in 2012 (Global Carbon Project, 2012).

Production can be enhanced on sustainable basis if BMPs are adopted to enhance C use efficiency. Soil is a analogous to bank account and balance of inputs and outputs must maintain with reference to sustaining both the environment and agriculture (Lal, 2007). It is, therefore, important to identify impact of management practices on the C cycle. Thus, this study was conducted with the objective to (i) evaluate C-equivalence of inputs and outputs to compute relative sustainability index of management system in dry land. The study was designed to test the hypothesis that minimum tillage with double cropping sequence among the best management practices (BMPs) are scale-neutral and enhance the C use efficiency in dry lands.

1. **Data sources and analyses**

Data related to biomass and grain yields were collected from rainfed region of northern Punjab, Pakistan. The experimental site is part of a wide rainfed track of northern Punjab called Pothwar plateau. The rainfall is of a bi-modal pattern with two maxima, the first in late summer (August and September) and the second during the winter-spring (February and March) (Fig. 1). The summer or monsoon rains constitute about 70 % of the total annual rainfall of 750-950 mm. The mean maximum temperature during summer ranges from 36 oC to 42 oC with extremes sometimes as high as 48 oC. These tillage systems were moldboard plough (MP, control), tine cultivator (TC) and minimum tillage (MT). Five cropping sequences testedwere: fallow–wheat (*Triticum aestivum*) (control), mungbean (*Vigna radiata*)–wheat, sorghum (*Sorghum bicolor*)–wheat, green manure–wheat and mungbean-chickpea (*Cicera rietinum*). The green manure crop comprised of a mixture of mungbean and sorghum, and ploughing under of the biomass before the grain setting stage.Weeds in fallow plots under MT were controlled with two sprays of roundup (glyphosate [N- (phosphonomethyl) glycine)] @ 1.5 liter ha.-1 Fertilization for mungbean, sorghum and wheat involved the application of 60 kg ha-1 urea, 100-50 kg ha-1 urea and diammonium phosphate (DAP), 120-80 kg ha-1 urea and DAP respectively, broadcasted and mixed in the surface soil layer at the time of seed bed preparation. The tractor used was Massey Ferguson (MF) 240 of 50 horse power at 2.250 rpm. Crops were seeded with a winter seed drill at row spacing of 15 cm. Soil of experimental site is clay loam with pH of 8, ECe of 0.25 dSm-1, bulk density of 1.4 Mg m-3, and nutrient concentration (mg kg-1 soil) of 3.35, 6.50 and 130 for N, P and K, respectively. Predominant soil of the site (33° 38' N, 73" 05' E) is classified as Inceptisols, Typic, Ustocrepts, loamy and Rawalpindi series (Govt. of Pakistan, 1974)

2.1 C-equivalenceinput

For the calculation of carbon inputs (from tillage systems, harvesting fertilizers and herbicides) common accounting methodology was used to calculate kg carbon equivalent per hectare (kg Ceq ha-1). The conventional tillage practice in Punjab is moldboard ploughing. For tillage operations (MP,TC and MT) all coefficients were obtained from Lal, (2004).For harvesting operations, data were given in terms of hours spent on each operation and then converted per hectare basis. Analogously, and taking winter wheat as a reference, a value of 0.72 kg Ceq ha-1 was used for carting (Koga *et al*. 2003), and 5.8 kg ha-1 for baling (Lal,2004).

Hidden C cost for N (91.3 kg CO2 e/kg N) and P (0.2 kg CO2 e/kg P) were those reported by Lal (2004). Direct emissions from addition of N-fertilizer are a major contributor to the C footprint due to the high global warming potential (GWP) of nitrous oxide, N2O. (Forster *et al.,* 2007).

2.2 C-equivalence out puts

Components of C out puts included grain yield, straw yield and root biomass. Output of C as root biomass carbon was estimated by using shoot: root (S:R) ratios using equation (1) and equation (2) (Bolinder, 1997).
$Cr=Yp \left(S: R –HI\right)×0.45$ ------------------------------------------ (Eq 1)

$CS =Yp\left(1-HI/HI\right)×0.45$ ------------------------------------------ (Eq 2)

Where, Cr is root carbon , Yp is the dry matter yield of above-ground biomass (kg ha-1), HI the harvest index (dry matter yield of grain/total above-ground dry matter yield) S: R is the shoot: root ratio Table 1.

2.3 Carbone Sustainability Index

Sustainability index is computed through equation given by (Lal, 2004)

Cs= (Co-Ci) /Ci

Where,*Cs* is sustainability index, *Co* is carbon output, and *Ci* is carbon input

 **3 Results and Discussion**

3.1 C-equivalence Inputs

C-based inputs in the farm operations were the same among both years from 2010-2012 fuel consumption in three tillage systems used (MP, MT and TC), increased with increase in depth of cultivation. Fuel consumption in MP ranges from 17-46 l ha-1(Collins *et al,* 1976, Lockeretz 1983, Stout, 1984 & Brows 1989). The average fuel consumption shown in Table 1. Fuel consumption in MP operated to 30 cm depth was 15.2 kg Ceq ha-1 with two ploughing per year, C input was 30.4 kg Ceq ha-1. Similarly, fuel consumption in TC operated to depth of 15 cm was 11.6 kg Ceq ha-1was used. In contrast one time ploughing was done with 3.2 kg Ceq ha-1 (Table 2).

Other field operations such as crop protection with herbicide used @ 1.5 l ha-1 in each season. Thus, total herbicide used based input 27.3 kg Ceq ha-1in summer and winter seasons. Fertilizer applied in both season at recommended dose of fertilizer was 3.64 kg Ceq ha-1addedby urea and 0.26 kg Ceq ha-1by DAP. Estimate of C input for in carting and baling was 1.47 and 36.53kg Ceq ha-1, respectively.

Research on fertilizer use in Pakistan was initiated in 1909, with the establishment of the Punjab Agriculture College at Lyallpur (now Faisalabad). The present recommended rate of NPK use is about 110kg ha-1. Recently, the objective of fertilizer research and development has shifted to improve fertilizer use efficiency, increase crop productivity and minimize adverse impact on the environment. Thus, C input is the one of the important driving variable for predicting the net rate of soil C sequestration (Bolinder *et al*., 2006). The continuous input of large amounts of biomass-C to the soil surface creates a positive C impact on agricultural and environmental sustainability ([Ferreira *et al*., 2012](http://www.sciencedirect.com/science/article/pii/S0167198713001785#bib0115)).

3.2 C-Equivalence out puts

The highest grain Ceq during the first year was under MP in winter with MW (1184kg Ceq ha-1) in Table 3. The highest grain Ceq In the second year, was estimated in summer with GW (1287 Kg EC ha-1) in Table 4. However, the highest biomass Ceq in first year was in winter with MC(1715 Kg Ceq ha-1). In summer, the highest biomass Ceq obtained in FW (1910 kg Ceq ha-1). However in the second year, the highest biomass Ceq was estimated in winter with FW (1656 kg Ceq ha-1) while in summer with MC (1910 kg Ceq ha-1). The highest Root Ceq in the first year was in winter with MC (11608 kg Ceq ha-1). However, in the second year it was in winter with MW (4652 kg Ceq ha-1) and in summer under MC (6944 kg Ceq ha-1).

The highest grain Ceq in the first year was under MT in winter with GW (1154 kg Ceq ha-1).In second year, it was with FW in (873 kg Ceq ha-1). The highest biomass Ceq in the first year was in MW(1584kg Ceq ha-1) in winter while in second year it was in summer with MW (1992kg Ceq ha-1). The highest root Ceq among the both year were in MC in winter and MW in summer (11635 and 9500kg Ceq ha-1), respectively. In the second year the highest roots Ceq was in summer with MW (10817 kg Ceq ha-1) in winter in FW (4241 kg Ceq ha-1). The highest the grain Ceq was under TC was in winter with GW (677kg Ceq ha-1).

From R:S ratio Ceq of out put was calculated from biomass leguminous crop have more reduced carbon as compare to cereals. (Table. 1). Legume crops are more responsive to atmospheric CO2. However in the second year, it was in winter with FW (713kg Ceq ha-1). In second year in the summer grain Ceq was highest in MW (116 kg Ceq ha-1). Biomass Ceq in winter in first year was obtained with MC (2246kg Ceq ha-1). In second year, in summer with MW (2128kg Ceq ha-1).The highest root Ce in first year was in winter crops with MC (12465kg Ceq ha-1). However, in the second year it was in summer with MW (8617kg Ceq ha-1). the highest root Ceq under MT was calculated in winter with MW (9500 kg Ceq ha-1) (Fig. 2)

Carbon in soil shoot on average taken about 0.45 percent and cereal crops translocate about 20-30 % total assimilated carbon into the soil (Kuzyakov, 2000) Carbon in the root was less comparative to shoot because that increased C inputs can promote soil organic carbon (SOC) turnover rates (Hoosbeek *et al.,* 2006, Phillips *et al*., 2012) via the priming effect (Kuzyakov *et al.,* 2000).

3.3 C-Sustainability Index

The highest C- Suitability index was under MT in MC between both years then MT and TC. In MT the highest *Cs* was under MC and followed by MW and it was relatively high than the MP. In TC trend was different the highest $Cs$was in winter with SW in first year while in second year in FW (Fig. 3).It was observed that the under MP utilization of C use efficiency was more except MC cropping sequence in second year in the MT tillage system than MP and CT. The maximum *Cs* was under MT with MC among both years in summer (77 and 130). However in the first year in winter it was the highest in MC (167) in second year it was in FW (82). The highest *Cs* was under MP in summer with MC both year (61 and 65), respectively. In winter in the first year it was highest in MC (100) and in second year it was with FW and MW (46, 45), respectively. The highest Cs was under TC among both years in summer was with MW (93, 95). In winter in first year with MC (133) and in second year SW (54), respectively.

Over all it was observed that legume crops with cereal in double cropping system under MT had more *Cs* than other sequence and tillage systems. Sustainability index differ according to the farm size in large farm and utilization of input in large farm carbon utilization more efficient than small farm it also depend open the C-based inputs.

1. **Conclusion**

Hypothesis was proved with the objectives and the data of C-equivalence of inputs and outputs and estimated sustainability index under different tillage systems and cropping sequences presented with the following conclusion:

* C sustainability in dray lands can be improve by shift of conventional tillage practices to minimum tillage with double cropping system in dry land agro ecosystem.
* The maximum C-use efficiency can be achieve if on long term basis proper use of BMPs according to field capacity under MT system with the double cropping sequence in dry land.

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Fig. 1. Mean monthly temperatures and rainfall during the experimental period.

Fig. 2. Mean of carbon- equivalence outputs from field crops from 2010-12 as influenced by tillage systems and cropping sequences

|  |  |
| --- | --- |
| Table 1 Shoot to root ratio of different crops |  |
| Crops | Shoot:Root | References |  |
| Wheat (*Triticumaestivum*) | 0.15 | Williams *et al*. (2013) |  |
| Mungbean (*Vignaradiata*) | 0.85 | Sangakkara (2003) |  |
| Sorghum (*Sorghum bicolor*) | 0.58 | Lacerda *et al.*(2006) |
| Greenmanure (Sorghum+Mungbean) | 0.71 | Ramos *et al*. (2005) |
| Chickpea (*Cicerarietinum*) | 1.04 | Bahavar*et al.* (2009) |

Table 2

C- Equivalence outputs from field crops in 2010-11 as influenced by tillage systems and cropping

sequences

|  |  |  |  |
| --- | --- | --- | --- |
| Form practices | No. of Farm operations | Total C- Cost | Carbon- Cost |
|  |  | ----------kg Ceq ha-1year -1---------- |
| Mouldboard plough | 2 |  30.4 | 15.2 |
| Minimum tillage | 1 |  3.2 | 3.2 |
| Tine cultivator | 2 |  11.6 | 5.8 |
| Herbicide | 3 |  27.3 | 9.1 |
| Urea | 2.8 |  3.64 | 1.3 |
| Diammonium phosphate (DAP) | 1.3 |  0.26 | 0.2 |
| Harvesting | 1 |  33.3 | 33 |
|  | Mouldboar plough based (kg Ceq ha-1year -1) = |  135 |  |
|  |  Tine cultivator based (kg Ceq ha-1year -1) = |  112 |  |
|  |  Minimum tillage based (kg Ceq ha-1year -1) = |  80.47 |  |

Tillage systems: MP, mouldboard plow; TC, tine cultivator and MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea

Table 3

Carbon- equivalence outputs from field crops from 2011-12 as influenced by tillage systems and cropping sequences

|  |  |  |
| --- | --- | --- |
| C-based outputs | Winter crop, 2010-11 | Summer crop, 2010 |
|  | FW | MW | SW | GW | MC | FW | MW | SW | GW | MC |
|  | Moldboard plough |
|  | -------------------------------------------------Ceq kg ha-1--------------------------------------- |
| Grain C  | 892 | 1184 | 793 | 760 | 351 | 0 | 103 | 0 | 0 | 104 |
| Biomass C | 1315 | 955 | 1207 | 1242 | 1715 | 0 | 1196 | 756 | 1625 | 1910 |
| Roots C | 3293 | 1644 | 3327 | 3601 | 11608 | 0 | 4474 | 0 | 0 | 6455 |
|    | Minimum tillage |
| Grain C  | 489 | 680 | 576 | 1155 |  318 | 0 |  83 |  0 |  0 | 108 |
| Biomass C | 958 | 650 | 870 | 700 | 1584 | 0 | 1851 | 761 | 1199 | 1518 |
| Roots C | 3998 | 1696 | 2986 | 1106 | 11635 | 0 | 9500 |  0 |  0 | 4677 |
|    | Tine cultivator |
| Grain C  | 587 | 630 | 677 | 536 | 305 | 0 |  0 | 0 | 133 |  91 |
| Biomass C | 1661 | 1669 | 1259 | 1515 | 2246 | 0 | 1489 | 701 | 555 | 1845 |
| Roots C | 6684 | 2310 | 2305 | 1987 | 12465 | 0 |  0 | 0 | 998 | 8617 |

Tillage systems: MP, mouldboard plow; TC, tine cultivator and MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea

Table 4

 C Carbon- equivalence outputs from field crops from 2011-12 as influenced by tillage systems and cropping sequences

|  |  |  |
| --- | --- | --- |
| C-based outputs | Winter crops, 2011-12 | Summer crops, 2011 |
|  | FW | MW | SW | GW | MC | FW | MW | SW | GW | MC |
|  | Moldboard plough |
|  | ----------------------------------kg ha-1------------------------------------------------------ |
| Grain C  | 712  | 712  | 1287  | 989  | 0  | 177  | 0  | 0  | 96  | 712  |
| Biomass C | 1448  | 1430  | 1549  | 539  | 0  | 1877  | 885  | 503  | 1910  | 1448  |
| Roots C | 4652  | 4587  | 2797  | 892  | 0  | 4531  | 0  | 0  | 6944  | 4652  |
|    | Minimum tillage |
| Grain C  | 779  | 692  | 843  | 697  | 0  | 80  | 0  | 0  | 65  | 779  |
| Biomass C | 815  | 894  | 1193  | 658  | 0  | 1992  | 615  | 1868  | 1683  | 815  |
| Roots C | 2022  | 2577  | 3083  | 1681  | 0  | 10817  | 0  | 0  | 8851  | 2022  |
|    | Tine cultivator |
| Grain C  | 655  | 635  | 595  | 463  | 0  | 116  | 0  | 0  | 129  | 655  | 635  |
| Biomass C | 1469  | 2044  | 1588  | 432  | 0  | 2128  | 1329  | 698  | 1534  | 1469  | 2044  |
| Roots C | 1457  | 1990  | 2097  | 1371  | 0  | 8617  | 0  | 0  | 998  | 1457  | 1990  |

Tillage systems: MP, mouldboard plow; TC, tine cultivator and MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea

**Fig. 3 Carbon sustainablity index under different tillage systams and cropping sequences**

****Tillage systems: MP, mouldboard plow; TC, tine cultivator and MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea