**ECOSYSTEM CARBON SUSTAINABILITY UNDER DIFFERENT C-EQUIVALENCE INPUTS AND OUTPUTS IN DRY LAND**

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*Abstract:*Efficient use of carbon (C) is principle goals of achieving agricultural and environmental sustainability. Thus, study was conducted to compare the C-equivalence (Ceq) of inputs and outputs and the C index of sustainability (Is). 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). Tillage systems included moldboard 14 plough (MP), deep tillage (DT) and minimum tillage (MT). The primary data collected were crop yield and the above ground biomass. Fuel utilization in MP was 15.2 kg Ceq ha-1 with two ploughing per year, C input was 30.4 kg Ceq ha-1. In DT it was 11.6 kg Ceq ha-1. Herbicide used based input 27.3 kg Ceq ha-1. 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, DT 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). However, the highest root Ceq under MT was calculated in winter with MW (9500 kg Ceq ha-1). Under MT, the maximum Iswas obtained with MC for both year in summer (77 and 130). In winter of the second year, the highest Iswas estimated for FW (82). These results showed that the efficient use of fertilizers, herbicides and farm machinery in the field under MT with legume based cropping system could be the best options to enhance the carbon Is in dry lands.

*Keywords:* C use efficiency; Index of Sustainability; C-equivalence inputs; C-equivalence outputs

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INTRODUCTION

Global carbon (C) emission and use efficiency have engrossed the international concern about environmental quality, global warming and sustainability of agricultural ecosystems 1. Therefore, the efficient utilization of C with recommended management practices is a use full tool in mitigating climate change and advancing agricultural sustainability 2,3. Emissions of greenhouse gases 70% increased by anthropogenic activities between 1970 and 2004, and it was estimated to increase further by 25% to 95% in 2030 4. Soils act in response as a source or sink of C it effected directly and indirectly by 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 agroecological conditions, different tillage and crop sequences act differently on (C) index of sustainability. However, in dry land reigns mostly minimum tillage (MT) with optimum crop residues and crop sequence decrease in rate of minerlization increase C storage and C index of sustainability 5. CO2 concentration in atmosphere has been increasing at a faster rate than the average over the past tenyears probably because of decrease in natural C sinks 6. The atmospheric concentration of CO2 reached 400 ppm in May 2013 7.

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 3, 8 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 9. Thus, changes in agricultural practices can also cause changes in C use efficiency 10, 11. For example, CO2 efflux from soil changes with change in tillage management 12, Minimum tillage (MT) systems reduce CO2 emissions from farm field operations 13. In addition, C emissions are directly related to fertilizer use 14, and to specific farming activities during crop production 15,16

Carbon index of sustainability can be attained by adopting practices which minimize the C-based inputs, maximize outputs, increase ecosystem services, and to improve the C use efficiency 3, 17 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 18. Increase in the flow of C into soils may be even more challenging because of the less quantity of residues returning trend into soil (Gupta, 2014). 19. The principal goal of organic farming and integrated farm management systems is to decrease the C losses from ecosystem which certainly have beneficial effect on the biodiversity within and around arable fields 20, 21, 22. Also there is an increasing emphasis on the need to de decarbonize the global economy 23, and to remove and sequester C in similar amounts as is produced through anthropogenic activities 24, 25, 26. Emission of CO2-C from land use, fossil fuel and cement production was 9.7 Pg C in 2012 by Le Quire 27. Production can be enhanced on sustainable basis if best management practices 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 28. 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 are scale-neutral and enhance the C use efficiency in dry lands.

EXPERIMENTAL

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) show Figure 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.



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

These tillage systems were moldboard 14 plough (MP, control), deep (DT) and minimum tillage (MT). Five cropping sequences tested were: 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 29.

C-EQUIVALENCE INPUT

For the calculation of (C) inputs (from tillage systems, harvesting fertilizers and herbicides) common accounting methodology was used to calculate kg (C) equivalent per hectare (kg Ceq ha-1). The conventional tillage practice in Punjab is moldboard 14 ploughing. For tillage operations (MP, DT and MT) all coefficients were obtained from RattanLal3. 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 30 and 5.8 kg ha-1 for baling reported by Rattan Lal3.

Estimates of 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-13. Hidden (C) cost also involve which release in farm of CO2 from fertilizers of nitrogen (91.3 kg CO2 e/kg N) and phosphorus (0.2 kg CO2 e/kg P) were those reported by 3. Direct emissions from addition of N-fertilizer are a major contributor to the C footprint due to the high global warming potential of nitrous oxide, N2O 31.

C-EQUIVALENCE OUTPUTS

Components of (C) outputs included grain yield, straw yield and root biomass. Output of (C) as root biomass (C) was estimated by using shoot: root (S:R) ratios using equation (1) and equation(2)32.

$Cr=Yp \left(S: R –HI\right)×0.45$ ------------------------------------------ (Eq 1)

$CS =Yp\left(1-\frac{HI}{HI}\right)×0.45$ ------------------------------------------ (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.

Table 1. Shoot to root ratio of different crops

|  |  |  |
| --- | --- | --- |
| Crops | Shoot:Root | References |
| Wheat (*Triticumaestivum*) | 0.15 | Williams *et al*. (2013) 33 |
| Mungbean (*Vignaradiata*) | 0.85 | Sangakkara (2003) 34 |
| Sorghum (*Sorghum bicolor*) | 0.58 | Lacerda *et al.*(2006) 35 |
| Greenmanure (Sorghum+Mungbean) | 0.71 | Ramos *et al*. (2008) 36 |
| Chickpea (*Cicerarietinum*) | 1.04 | Bahavar*et al.* (2009) 37 |

CARBONE INDEX OF SUSTAINABILITY

Index of sustainability is computed through equation given by 3

$$Is=\frac{\left(Co-Ci\right)}{Ci }$$

Where, Is (C) index of sustainability, *Co* is (C) output, and *Ci* is carbon input.

RESULTS AND DISCUSSION

C-EQUIVALENCE INPUTS

Carbon based inputs in the farm operations were the same among both years from 2010-2012 Fuel consumption in three tillage systems (MP, MT and DT), increased with increase in depth of cultivation. Fuel consumption in MP ranges from 17-46 l ha-1 38, 39, 40, 41. The average fuel consumption shown in Table 1. In MP operated to 30 cm depth fuel consumption 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 DT operated to depth of 15 cm was 11.6 kg Ceq ha-1. 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.

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---------- |
| Moldboard 14 plough | 2 | 30.4 | 15.2 |
| Minimum tillage | 1 | 3.2 | 3.2 |
| Deep tillage | 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 |  |
| Deep tillage based (kg Ceq ha-1year -1) = |  | 112 |  |
| Minimum tillage based (kg Ceq ha-1year -1) = |  | 80.47 |  |

Tillage systems: MP, moldboard plow; DT, deep tillage and MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea

Fertilizer applied in both season at recommended dose of fertilizer was 3.64 kg Ceq ha-1added by 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 32. The continuous input of large amounts of biomass (C) to the soil surface creates a positive C impact on agricultural and environmental sustainability 42.

C-EQUIVALENCE OUTPUTS

The highest grain Ceq during the first year was under MP in winter with MW (1184kg Ceq ha-1) in Table 3.

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

Tillage systems: MP, moldboard plow; DT, deep tillage and MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea

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 (4587 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(1584 kg Ceq ha-1) in winter while in second year it was in summer with MW (1992 kg Ceq ha-1).

Table 4. C Carbon- equivalence outputs from field crops from 2011-12 as influenced by tillage systems and cropping sequences

|  |  |  |
| --- | --- | --- |
| C-based outputs | Winter crop, 2011-12 | Summer crop, 2011 |
|  | FW | MW | SW | GW | MC | FW | MW | SW | GW | MC |
| Moldboard 14 plough |
| ------------------------Ceq kg ha-1---------------------------- |
| Grain carbon | 712  | 712  | 1287  | 989  | 0  | 177  | 0  | 0  | 96  | 712  |
| Biomass carbon | 1448  | 1430  | 1549  | 539  | 0  | 1877  | 885  | 503  | 1910  | 1448  |
| Roots carbon | 4652  | 4587  | 2797  | 892  | 0  | 4531  | 0  | 0  | 6944  | 4652  |
| Minimum tillage |
| Grain carbon | 779  | 692  | 843  | 697  | 0  | 80  | 0  | 0  | 65  | 779  |
| Biomass carbon | 815  | 894  | 1193  | 658  | 0  | 1992  | 615  | 1868  | 1683  | 815  |
| Roots carbon | 2022  | 2577  | 3083  | 1681  | 0  | 10817  | 0  | 0  | 8851  | 2022  |
| Deep tillage |
| Grain carbon | 655  | 635  | 595  | 463  | 0  | 116  | 0  | 129  | 655  | 635  |
| Biomass carbon | 1469  | 2044  | 1588  | 432  | 0 | 2128  | 698  | 1534  | 1469  | 2044  |
| Roots carbon | 1457  | 1990  | 2097  | 1371  | 0 | 8617  | 0  | 998  | 1457  | 1990  |

Tillage systems: MP, moldboard 14 plough; , deep tillage and MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea.

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 DT was in winter with GW (677kg Ceq ha-1).

Carbon in soil shoot on average taken about 0.45 percent and cereal crops translocation about 20-30 % total assimilated (C) into the soil 43 Carbon in the root was less comparative to shoot because that increased C inputs can promote soil organic carbon (SOC) turnover rates 44, 45 via the priming effect 43.

CARBON- INDEX OF SUSTAINABILITY

The highest C- Index of Suitability was under MT in MC between years then MT and DT. In MT the highest *Cs* was under MC and followed by MW and it was relatively high than the MP. In DT trend was different the highest $Cs$ was in winter with SW in first year while in second year in FW show Figure 2. 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 DT 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. Index of sustainability differ according to the farm size in large farm and utilization of input in large farm (C) utilization more efficient than small farm it also depends open the C-based inputs.

CONCLUSION

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

* C-equivalent values for minimum tillage with legumes crops provide highest index of sustainability
* 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 achieved on long term basis with proper use of BMPs according to field capacity under MT system with the double cropping sequence in dry land.



**Fig. 2. Carbon index of sustainablity (Is) under different tillage systams and cropping sequences**

Tillage systems: MP, moldboard plow; DT, deep tillage MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea

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