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Ecosystem carbon sustainability under different C-equivalence inputs and outputs in dry land

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Abstract: The efficient use of carbon is the principle goal of achieving the agricultural and environmental sustainability. Thus, study was aimed to compare the C-equivalence (C_{eq}) of inputs and outputs and the C index of sustainability (*Is*). Five cropping sequences were; fallow–wheat (FW, *Triticum aestivum*) (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 C_{eq} ha^{-1} with two ploughing per year, C input was 30.4 kg C_{eq} ha^{-1}. In DT it was 11.6 kg C_{eq} ha^{-1}. Herbicide used based input was 27.3 kg C_{eq} ha^{-1}. The C_{eq} of outputs differed among tillage treatments, and were: 135, 112 and 80.47 kg C_{eq} ha^{-1} for MP, DT and MT, respectively. On the average of two years, the highest grain C_{eq} was measured under MP and under SW in winter (1040 kg C_{eq} ha^{-1}). The maximum C_{eq} biomass was estimated in winter with MC (2867 kg C_{eq} ha^{-1}). However, the highest root C_{eq} under MT was calculated in winter with MW (9500 kg C_{eq} ha^{-1}). Under MT, the maximum Is was obtained with MC for both years in summer (77 and 130). In winter of the second year, the highest *Is* was 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 option 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 the use efficiency have engrossed the international concern about the 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 diminishing the climate change and advancing the agricultural sustainability.[2,3] Emissions of greenhouse gases were increased by 70 % because of anthropogenic activities between 1970 and 2004, and it was estimated they would have increased further by 25 to 95 % in 2030.[4] Soil acts as a source or a sink for atmospheric carbon released by anthropogenic activities. The evaluation of soil and the ecosystem C budgets are important to determine whether soil acts as a source or a sink of C under different management practices. In diverse agroecological conditions, the different tillage and crop sequences act differently on the (C) index of sustainability. However, in dry land regions mostly minimum tillage (MT) with the optimum crop residues and crop sequence decrease in the rate of mineralization, which increases C storage and C index of sustainability.[5] CO_2 concentration in atmosphere has been increasing at a faster rate than the average one over the past ten years, probably because of the decrease in natural C sinks.[6] The atmospheric concentration of CO_2 reached 400 ppm in May 2013.[7]

The carbon use efficiency is determined by assessing C-based inputs and outputs used in farm operations determining the quantity of soil and efficiency of the agro ecosystems[3,8] observed that the 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 the estimates of grain yield, straw yield, and root biomass.[9] Thus, changes in agricultural practices can also cause changes in the C use efficiency.[10,11] For example, CO_2 efflux from soil changes with the change in tillage management,[12] The minimum tillage (MT) systems reduce CO_2 emissions from farm field operations.[13] In addition, the C emissions are directly related to the fertilizer use,[14] and to the specific farming activities during the crop production.[15,16]

The carbon index of sustainability can be obtained by the adopting practices which minimize the C-based inputs, maximize outputs, increase ecosystem services, improve the C use efficiency,[3,17] suggesting that the adaptation of the conservation tillage with the reduced frequency of the summer fallowing with the 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 *et al*.).[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.[20–22] Also there is an increasing emphasis on the need to decarbonise the global economy,[23] and to remove and separate C in similar amounts as is produced through anthropogenic activities.[24–26] Emission of CO_2-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 an analogous to bank accounts and balance of inputs and outputs, and therefore it must be maintained with regard of sustaining both the environment and agriculture.[28] It is, therefore, important to identify the impact of management practices on the C cycle. Thus, this study was conducted with the objective to evaluate the C-equivalence of inputs and outputs to compute the relative sustainability index of management system in dry land. The study was designed to test the hypothesis that minimum tillage with double cropping sequence was among the best management practices are scale-neutral and enhanced the C use efficiency in dry lands.

EXPERIMENTAL

Data sources and analyses

Data related to biomass and grain yields were collected from the 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), shown in 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 to 42 °C with extremes sometimes as high as 48 °C.

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 L 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. The soil of the experimental site is clay loam with pH of 8, *ECe* of 0.25 dS m^{-1}, bulk density of 1.4 mg m^{-3}, and the 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]

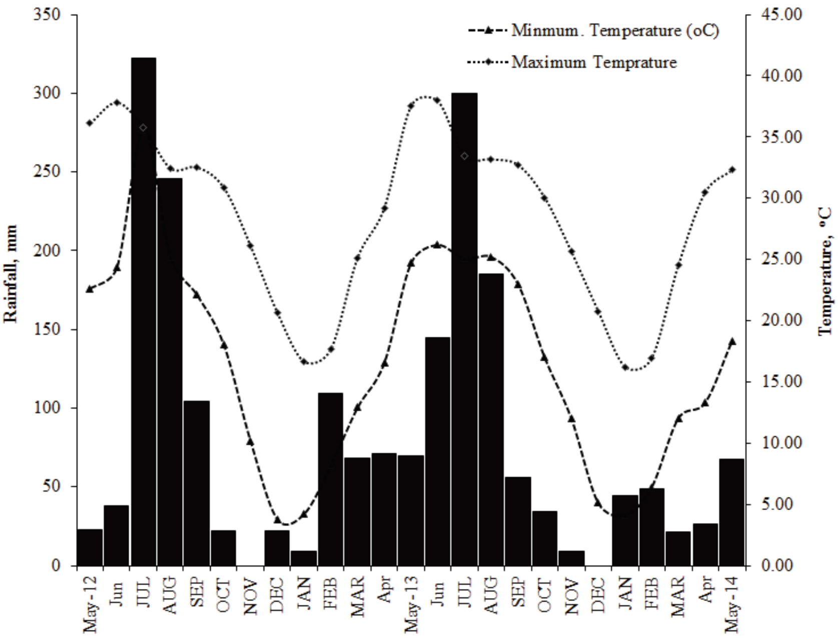

Fig. 1. Mean monthly temperatures and rainfall during the experimental period.

C-equivalence input

For the calculation of (C) inputs (from tillage systems, harvesting fertilizers and herbicides) the common accounting methodology was used to calculate kg (C) equivalent per ha (kg C_{eq} ha^{-1}). The conventional tillage practice in Punjab is the moldboard 14 ploughing. For tillage operations (MP, DT and MT) all coefficients were obtained from Rattan Lal.[3] 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 C_{eq} ha^{-1} was used for carting[30] and 5.8 kg ha^{-1} for baling reported by Rattan Lal.[3]

The estimates of C emissions in kg C_{eq} 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, the estimates of C emissions (kg C_{eq} ha^{-1}) for different fertilizer nutrients are 0.9–1.8 for N, 0.1––0.3 for P_2O_5, and 0.1–0.2 for K_20. An estimate of C emission by herbicides is 5–6 kg C_{eq} kg^{-1}. It was reported[3] that hidden (C) cost involves the release of CO_2 from fertilizers of nitrogen (91.3 kg CO_2 e/kg N) and phosphorus (0.2 kg CO_2 e/kg P). Direct emissions from the addition of N-fertilizer are a major contributor to the C footprint due to the high global warming potential of nitrous oxide, N_2O.[31]

C-equivalence outputs

Components of (C) outputs included grain yield, straw yield and root biomass. The output of (C) as the root biomass (C) was estimated using the shoot : root (S:R) ratios in Eqs. (1) and (2):[32]

$$Cr = Yp\left(S:R - HI\right)\times 0.45 \tag{1}$$

$$CS = Yp\left(1-\frac{HI}{HI}\right)\times 0.45 \quad (2)$$

where *Cr* is the root carbon concentration, *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 I.

TABLE I. Shoot to root ratio of different crops

Crop	Shoot:Root	Reference
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 calculated by the following equation:[3]

$$Is = \frac{Co - Ci}{Ci}$$

where *Is* is (C) index of sustainability, *C*o is (C) output, and *C*i is carbon input.

RESULTS AND DISCUSSION

C-equivalence inputs

The carbon based inputs in the farm operations were the same among the years from 2010–2012 fuel consumption in three tillage systems (MP, MT and DT), increased with the growth in cultivation. The fuel consumption in MP ranges from 17–46 L ha^{-1}.[38–41] The average fuel consumption is shown in Table I. In MP which operated to 30 cm depth, the fuel consumption was 15.2 kg C_{eq} ha^{-1} with two ploughing per year and the C input was 30.4 kg C_{eq} ha^{-1}. Similarly, the fuel consumption in DT which operated to depth of 15 cm was 11.6 kg C_{eq} ha^{-1}. In contrast, one time ploughing was done with MT of 3.2 kg C_{eq} ha^{-1} (Table II). Other field operations such as crop protection with herbicide used 1.5 l ha^{-1} in each season. Thus, the total herbicide used based input was 27.3 kg C_{eq} ha^{-1} in summer and winter seasons.

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

The fertilizer applied in both seasons at the recommended dose was 3.64 kg C_{eq} ha^{-1} of urea and 0.26 kg C_{eq} ha^{-1} of DAP. The estimate of C input for carting and baling was 1.47 and 36.53kg C_{eq} ha^{-1}, respectively.

Research on the 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 (nitrogen, phosphorous and potassium) use is about 110kg ha^{-1}. Recently, the objective of the fertilizer research and development has shifted to the improvement of the fertilizer use efficiency, the increase of the crop productivity and the minimizing of the unfavourable impact on the environment. Thus, C input is the one of the important variables for predicting the net rate of soil C sequestration.[32] The continuous input of the large the amounts of biomass (C) to the soil surface creates a positive C impact on agricultural and environmental sustainability.[42]

TABLE II. 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 C_{eq} ha^{-1} year^{-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 C_{eq} ha^{-1} year^{-1}	–	135	–
Deep tillage based, kg C_{eq} ha^{-1} year^{-1}	–	112	–
Minimum tillage based, kg C_{eq} ha^{-1} year^{-1}	–	80.47	–

C-equivalence outputs

The highest grain C_{eq} during the first year was under MP in winter with MW (1184 kg C_{eq} ha^{-1}) in Table III.

TABLE III. Carbon-equivalence outputs (C_{eq} kg ha^{-1}) from field crops from 2011-12 as influenced by tillage systems and cropping sequences; 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

C-based output	Winter crop, 2010-11					Summer crop, 2010				
	FW	MW	SW	GW	MC	FW	MW	SW	GW	MC
Moldboard 14 plough										
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

The highest grain C_{eq} in the second year, was estimated in summer with GW (1287 kg EC ha^{-1}) in Table IV. However, the highest biomass C_{eq} in the first year was in winter with MC (1715 kg C_{eq} ha^{-1}). In summer, the highest biomass C_{eq} was obtained in FW (1910 kg C_{eq} ha^{-1}). However in the second year, the highest biomass C_{eq} was estimated in winter with FW (1656 kg C_{eq} ha^{-1}) while in summer it was with MC (1910 kg C_{eq} ha^{-1}). The highest Root C_{eq} in the first year was in winter with MC (11608 kg C_{eq} ha^{-1}). However, in the second year it was in winter with MW (4587 kg C_{eq} ha^{-1}) and in summer with MC (6944 kg C_{eq} ha^{-1}).

TABLE IV. C Carbon-equivalence outputs (C_{eq} kg ha^{-1}) from field crops from 2011–2012 as influenced by tillage systems and cropping sequences; 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

C-based output	Winter crop, 2011-12					Summer crop, 2011				
	FW	MW	SW	GW	MC	FW	MW	SW	GW	MC
Moldboard 14 plough										
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

The highest grain C_{eq} in the first year was under MT, in winter with GW (1154 kg C_{eq} ha^{-1}). In the second year, it was with FW (873 kg C_{eq} ha^{-1}). The highest biomass C_{eq} in the first year was with MW (1584 kg C_{eq} ha^{-1}), in winter, while in second year it was in summer, with MW (1992 kg C_{eq} ha^{-1}).

The highest root C_{eq} among both years were in MC in winter and MW in summer (11635 and 9500 kg C_{eq} ha^{-1}), respectively. In the second year the highest roots C_{eq} was in summer with MW (10817 kg C_{eq} ha^{-1}) in winter with FW (4241 kg C_{eq} ha^{-1}). The highest grain C_{eq} was under DT was in winter with GW (677 kg C_{eq} ha^{-1}).

The carbon in plant shoot on average was taken at about 0.45 %, and cereal crops at about 20–30 %, of total (C) assimilated into the soil.[43] Carbon in the root was less comparative to shoot because the increased C inputs can promote soil the organic carbon (SOC) turnover rates[44, 45] *via* the priming effect.[43]

Carbon-index of sustainability

The highest C-Index of suitability (*Is*) was under MT with MC in all examined years, then MT with DT. With MT the highest *Is* was under MC and followed by MW and it was relatively higher than the MP. In DT the trend was different, the highest C_s was in winter with SW in first year while in second year in FW as shown in Fig. 2. It was observed that the under MP utilization of C use was more efficient, except for the MC cropping sequence in second year in the MT tillage system, than MP and CT. The maximum C_s was under MT with MC among both years in summer (77 and 130). However, in the first year in winter it was the highest with MC (167), and in second year it was with FW (82). The highest C_s was under MP in summer with MC both year (61 and 65), respectively. In winter in the first year it was the highest in MC (100) and in second year it was with FW and MW (46 and 45), respectively. The highest C_s was under DT among both years in summer was with MW (93 and 95). In winter in the first year it was the highest with MC (133) and in second year with SW (54), respectively.

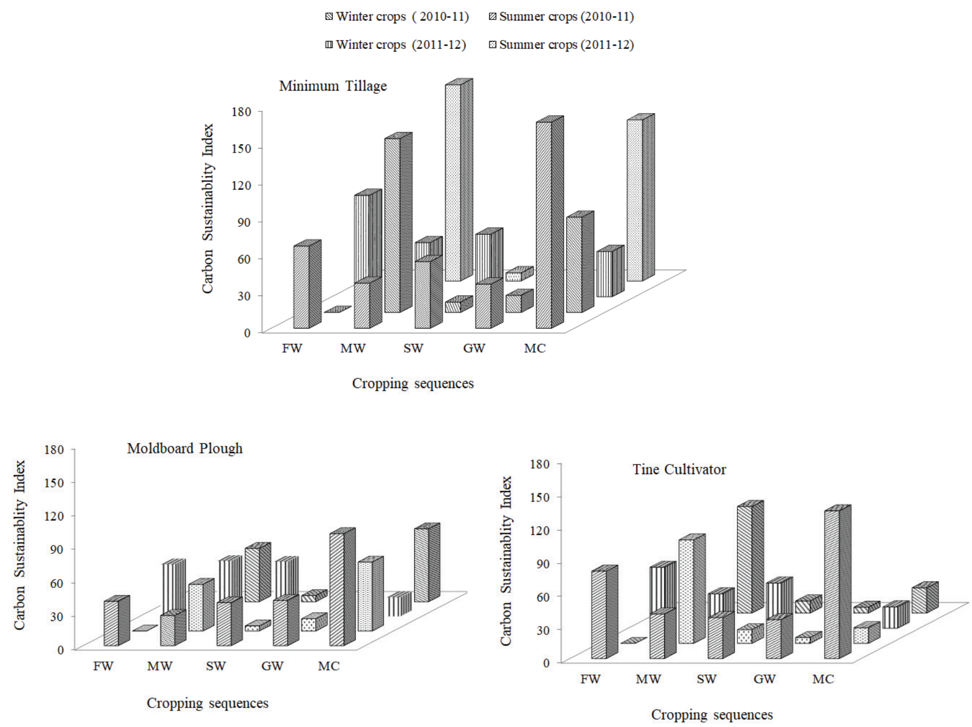

Fig. 2. Carbon index of sustainablity (I_s) under different tillage systams and cropping sequences; tillage systems: MP, moldboard plow; DT, deep tillage MT, minimum tillage. Crop sequences: FW, fallow-wheat; MW, mungbean-wheat; SW,sorghum-wheat; GW, green manure-wheat; MC, mungbean-chickpea.

Overall it was observed that the legume crops with cereal in double cropping system under MT had higher *Is* than other sequence and tillage systems. The C--index of sustainability (*Is*) differ according to the farm size. In large farm utilization of carbon based inputs are more efficient than small.

CONCLUSION

Hypothesis was proved with the objectives and the data of the C-equivalence of inputs and outputs and the 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 dryland can be improved by shift of conventional tillage practices to minimum tillage with double cropping system in dryland 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.

ИЗВОД

УГЉЕНИЧНА ОДРЖИВОСТ ЕКОСИСТЕМА ПОД РАЗЛИЧИТИМ УЛАЗНИМ И ИЗЛАЗНИМ ВРЕДНОСТИМА C-ЕКВИВАЛЕНЦИЈЕ У СУВОМ ЗЕМЉИШТУ

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Ефикасно коришћење угљеника је принципијелни циљ постизања одрживости аграра и животне средине. Ова студија је спроведена ради поређења C-еквиваленције (C_{eq}) на улазним и излазним токовима и индекса одрживости C (*Is*). Пет испитиваних култура су биле: смена озиме пшенице и угара, смена мунго пасуља и пшенице, смена сирка за зрно и пшенице, смена зеленишног ђубрења и пшенице, смена мунго пасуља и наута. Системи обраде су обухватали: орање (класични раони плуг), дубоку обраду и минималну обраду. Примарни подаци су били принос и надземна биомаса. Утрошак горива код MP је био 15,2 kg C_{eq} ha^{-1} уз два орања годишње, C улаз је био 30,4 kg C_{eq} ha^{-1}. Код DT је био 11,6 kg C_{eq} ha^{-1}. Улазна количина због хербицида била је 27,3 kg C_{eq} ha^{-1}. Излазни C_{eq} се разликовао од једног до другог тањирања, и то: 135, 112 и 80,47 kg C_{eq} ha^{-1} за MP, DT и MT, редом. На основу средње двогодишње вредности C_{eq} највиша вредност C_{eq} зрна била је измерена при MP и SW зими (1040 kg C_{eq} ha^{-1}). Максимална вредност C_{eq} биомасе била је процењена у зиму уз MC (2867 kg C_{eq} ha^{-1}). Међутим, највиша вредност C_{eq} за корен при MT била је израчуната зими код MW (9500 kg C_{eq} ha^{-1}). Уз MT, максимална вредност *Is* добијена је уз MC за обе године лети (77 и 130). У зиму друге године, највиша вредност за *Is* процењена је за FW (82). Ови резултати су показали да ефикасно коришћење ђубрива, хербицида и пољопривредне механизације на терену под условима MT са системом за узгајање легума може да буде најбољи начин да се побољша угљенични *Is* на сувом земљишту.

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REFERENCES

1. J. M. Kimble, R. Lal, R. F. Follett, in *Assessment methods for soil carbon. Advances in Soil Science*, R. Lal., J. M. Kimble, B. Follett, Eds., CRC press, Boca Raton, FL, 2001, p. 12
2. IPCC, *Land use, land-use change, and forestry*, Cambridge University Press, Cambridge, 2000
3. R. Lal, *Environ. Int.* **30** (2004) 981
4. S. K. Rose, B.A. McCarl, *Choices* **23** (2008) 15
5. M., S Upendra, W. L. Andrew, C. T. Thecan, D. J Jalal, T. L. Robert, R G.E. Orbet, L.A. Brett, *Open J. Soil Sci.* **2** (2008) 242
6. J. G. Canadell, C. Le Quéré, M. R. Raupach, C. B. Field, E. T. Buitenhuis, P. Ciais, T. J. Conway, N. P. Gillett, R. A. Houghton, G. Marland, *Proc. Int. Acad. Sci.* **104** (2007) 18866
7. D. Carrington, *Global carbon dioxide in atmosphere passes milestone level*, The Guardian, https://www.theguardian.com/environment/2013/may/10/carbon-dioxide-highest-level-greenhouse-gas (2013)
8. T. O. West, G. Marland, A. W. King, W. M. Post, A. K. Jain, K. Andrasko, *Environ. Manage*. **33** (2004)507
9. Dubey, A. R. Lal, *J. Crop Improv.* **23** (2009) 332
10. K. Paustian, J. Six, E. Elliott, H. Hunt, *Biol. Geol. Chem.* **48** (2000) 147
11. T. West, G. Marland, *Environ. Pollut*. **116** (2002) 439
12. T. Aslam, M. Choudhary, S. Saggar, *Agric. Ecosys. Environ*. **77** (2000) 257
13. S. Malhi, R. Lemke, *Soil Till. Res*. **96** (2007) 269
14. S. L. Choudrie, G. Tlethwaite, *UK greenhouse gas inventory, 1990–2006. Annual report for submission under the framework convention on climate change*, AEA Group, Oxfordshire, 2008
15. P. R. Adler, S. D. Grosso, W. J. Parton, *Applied Ecol.* **17** (2007) 675
16. S. St. Clair, J. Hillier, P. Smith, *Biomass Bioenergy* **32** (2008) 442
17. R. A. Gill, H. W. Polley, H. B. Johnson, L. J. Anderson, H. Maherali, R. B. Jackson, *Nature* **417** (2002) 279
18. S. M. T. A. Adi, *Trends Agric. Ecol*. **1** (2008) 14
19. C. Gupta, S. S. Srivastava, R. Singh, S. Chaudhari, D. Sharma, S. Singh, D. Sarkar, *Soil Till. Res*. **136** (2014) 76
20. G. Squire, S. Rodger, G. Wright, *Ann. Appl. Biol.* **136** (2000) 47
21. R. A. Robinson, W. J. Sutherland, *J. Appl. Ecol*. **39** (2002) 157
22. E. Marshall, V. Brown, N. Boatman, P. Lutman, G. Squire L. Ward, *Weed Res*. **43** (2003) 77
23. P. Newell, M. Paterson, *Biomass Biol. Energy* **32** (2010) 442
24. G. Bridge, *Prog. Hum. Geogr*. **35** (2011) 820
25. A. Bumpus, D. Liverman, *Global Polit. Econ*. (2010) 203
26. H. Lovell, D. Liverman, *New Polit. Econ*. **15** (2010) 255
27. C. Le Quéré, R. J. Andres, T. Boden, T. Conway, R. A. Houghton, J. House, *The global carbon budget 1959–2011. Earth Syst. Sci. Data Discuss*. **5.2** (2012) 1107
28. R. Lal, *Science* **304** (2007) 1623
29. Goverment of Pakistan, *Soil Series Key and Soil Classification. Soil Survey of Pakistan*, Ministry of Food and Agriculture, Lahore, 1974, p. 133
30. N. H. Koga, Tsuruta, H. Tsuji, H. Nakanoa, *Agric. Ecosys. Environ*. **99** (2003) 213

31. D. Foster, F. Swanson, J. Aber, I. Burke, N. Brokaw, D. Tilman, A. Knapp. *Biol. Sci*. **53** (2003) 77
32. M. Bolinder, H. Janzen, E. Gregorich, D. Angers, A. B. Vanden, *Agric. Ecosys. Environ.* **118** (2007) 29
33. J. D. Williams, D. K. McCool, C. L. Reardon, C. L. Douglas, S. L. Albrecht, R. W. Rickman, *J. Soil Water Conserv*. **68** (2013) 349
34. U. R. Sangakkara, P. Stamp, A. Soldati, M. Liedgens, *J. Agron.* **19** (2002) 225
35. C. F. Lacerda, J. Cambraia, C. Mao, J. T. Prisco, M. A. Olivia, *Rev. Cien. Agron*. **37** (2006) 110
36. S. B. Ramos, J. M. Barriuso, D. L. L Pereyra, J. Domenech, F. J. M. Gutierrez, *Phytopathol*. **98** (2008) 451
37. N. Bahavar, A, Ebadi, A. Tobeh, E.S. Jamaati. *Soil Res. J. Environ. Sci.* **3** (2009) 332
38. N. E. Collins, L. J. Kimble, T. H. Williams, in *Agriculture and Energy*, W. Lockeretz (Ed.), Academic Press, New York, 1976, pp. 233–236
39. W. Lockeretz, *Soil Water Conserv.* **38** (1983) 207
40. B. A. Stout, in *Energy use and Management in Agriculture*, M. A. Breton (Ed.), North Scituate, MA, 1984
41. C. G. Bowers, *Trans. ASAE* **32** (1989) 1492
42. K. N. Ferreira, T. M. Iverson, K. Maghlaoui, J. Barber, S. Iwata, *Science* **303** (2004) 1831
43. Y. Kuzyakov, G. Domanski, *J. Plant Nutr. Soil Sci*. **163** (2000) 421
44. M. R. Hoosbeek, Y. G. Li, Scarascia, E. Mugnozza, *Plant Soil.* **281** (2006) 247
45. R. P. Phillips, I. C. Meier, E. S. Bernhardt, A. S. Grandy, K. Wickings A. C. Finzi, *Ecology* **15** (2012) 1042.