

Evaluation of CENTURY Model for Soil Organic Carbon Assessment at Different Cropping Patterns in Semi-Arid Subtropical India

N. J. SINGH¹*, M. KUDRAT², AND K. JAIN³

¹ School of Natural Resource Management, College of Post Graduate Studies, Central Agricultural University, Umiam, Meghalaya

² Indian Institute of Remote Sensing (IIRS), Dept. of Space, ISRO, Dehradun, Uttarakhand, India
E-mail: kudrat.isro@gmail.com

³ Indian Institute of Technology-Roorkee, Roorkee, Uttarakhand, India E-mail: kjainfce@iitr.ac.in

* Corresponding Author; email: naorem2005@gmail.com

ABSTRACT

The CENTURY model was evaluated for its ability to simulate soil organic carbon (SOC) changes at different cropping patterns of Uttar Pradesh. A long-term fertilizer trial on rice-wheat system at Ludhiana, Punjab was used for the necessary parameters needed to run Century. This trial was conducted at semi-arid subtropical (mean annual rainfall 800 mm, mean temperature 6.7-35°C) with different treatment combinations. The modeling efficiency (ME) of this trial was 0.87, 0.93 and 0.97 for the treatments wheat straw (WS)+Urea-N (amount of added NPK: 176, 3.3, 61 kg ha⁻¹) (T4), WS+ green manure (GM)+Urea-N (amount of added NPK: 176, 3.3, 61 kg ha⁻¹) (T5) and farm yard manure (FYM)+GM (amount of added NPK: 186, 35, 81 kg ha⁻¹) (T7) respectively and r² for all treatments was more than 0.9. The SOC storage at different cropping systems was found in the following order: rice-wheat > sugarcane- wheat > maize-wheat > jowar-pulses/ oilseed. The anaerobic part of rice-wheat system and minimum tillage practices under sugarcane- wheat system might enhance the SOC storage at the similar agro-climatic condition.

Key Words: Biomass, Century Model, Rice-wheat, Long Term Experiment, Minimum Tillage Practices

INTRODUCTION

Soil carbon is an important component of soil which plays a vital role for the enhancement of soil productivity and agricultural sustainability. It has also importance in the global carbon cycle of mitigation or worsening of atmospheric CO₂ level. Soil Organic Carbon (SOC) is highly sensitive to land use changes (Bhattacharyya et al. 2010, Powlson 2005). There is greatest land use change in the tropics since the demand for food and land is increasing with the increase in population. Tropical agriculture currently feeds 70% of the world population (Lal and Sanchez 1992). Much of this demand is being met by converting native ecosystems to cultivated and cultivate more and more of our rapidly shrinking per capita land resources. The shrinking of agricultural land

and the demand for more food production would call for multiple cropping in a single piece of land. Cropping pattern can have significant environmental consequences thereby releasing C from soils to the atmosphere (Houghton et al. 2000). Hence there is a need to pay more attention to better management of agricultural systems. Subsequent poor soil and crop management can lead to further depletion of SOC. Despite the importance of tropical areas in terms of the percentage of global SOC stocks and the vulnerability of these stocks (Batjes 1996) but we have little information of SOC at different interaction of soils and land use/land management practices. The increasing realization of agricultural land management is an integral part of a global carbon stock, the need for soil carbon models to simulate agricultural cropping rotations is recognized and modeling of soil

carbon dynamics can also help in selecting the most promising soil management practices. Carbon models are used for analysing and predicting changes in the content of soil organic matter (SOM) based on current understanding of soil carbon dynamics. Modeling provides a means by which the overall feasibility of a variety of land management technologies and practices can be assessed. Modeling of soil carbon dynamics helps in selecting the most promising soil management practices for further investigation. Field experiment coupled with simulation models is useful for understanding the dynamics of SOC as influenced by complex interactions of soil, land use and management, and climate (Poussart et al. 2004, Pretty et al. 2006). This research will help in generating the database of soil carbon status at different cropping systems under intensive cultivation of Uttar Pradesh at similar agro-climatic conditions and can also help in forecasting the soil fertility and provide scientific information for good SOC management.

STUDY AREA

The study was conducted at different locations of semi-arid sub-tropical Uttar Pradesh, Indo-Gangetic plain of India (23° 52' to 30° 24' N latitude and 77° 05' to 84° 38' E longitude) with semi-arid subtropical environment (1,200 mm annual rainfall and 5°C to 45°C average temperature) (Anonymous 2005) and divided into three physiographical regions (viz. the northern mountains of Siwaliks, the southern hills and plateau, and the vast alluvial Gangetic plains between the two). Soils are developed over alluvium brought by the rivers (i.e. the Ganga, the Yamuna, the Ramganga, the Gomati and the Ghaghra). The soil texture varies from coarse loamy to fine loamy. The dominant soil orders are Inceptisols followed by Alfisols. Small amount of Vertisols and Entisols are also found in the study area (Singh et al. 2004). The Entisols are confined to Siwalik Hill, active flood plain and recent alluvial plains. Vertisols are occurring in the Bundelkhand region.

Land Use Land Cover and Cropping Pattern

The major land use/land cover of the study site is characterized by agriculture, forests, and horticultural plantations, barren rocks and scrubs, settlements, wastelands and water bodies. Twelve different cropping patterns were delineated and mapped in the Indo-Gangetic plain of Uttar Pradesh. The forests covered

about 6.32% of the total geographical area. The net cropped area was 20,282,159 ha (84.18% of the total geographical area) and the non-agricultural area observed was 34,37,376 ha (14.26% of the total geographical area). Rice was the single most dominant crop of the state, occupying about 32.94% of the total geographical area during the kharif season. Maize/jowar was the second major cereal crop, accounting for 13.77% of the total geographical area of the state. The major crops grown during the rabi season were wheat and pulses/oilseed, covering areas of 79,79,268 ha (33.12%) and 59,74,743 ha (24.80%), respectively. Rice-wheat, sugarcane and rice-pulses were the major cropping patterns, occupying about 39,58,740 ha (16.43%), 36,09,940 ha (14.98%) and 25,11,298 ha (10.42%), respectively. The areas under pulses/oilseed were significantly higher in the rabi season. Sugarcane-wheat and pulses shared an almost equal area (6.49%). The maize/jowar-wheat cropping pattern occupied 6.14% of the total geographical area of the state. Single cropping patterns (i.e. rice-fallow, fallow-pulses, fallow-wheat, maize-fallow and sugar-cane-fallow) were minor, occupying 6.08, 2.94, 4.06, 2.69 and 2.51%, respectively. Wasteland, including gully, salt-affected, waterlogged and rocky land, accounted for 3.80% of the total geographical area (Singh et al. 2011).

MATERIALS AND METHODS

Soil Sampling

Undisturbed soil samples were collected to measure the soil bulk density (ρ_b) for each soil layer using the core method (Blake and Hartge 1986). The cores from 0- to 15- to 30- cm soil layers were taken in the middle part of the corresponding layer using a core sampler. Soil samples were collected by digging pits with dimensions of 20 cm (width) by 20 cm (length) by surface layers (e.g., 0–15, and 15–30 cm layers) from four dominant major cropping patterns (i.e. rice-wheat, sugarcane-wheat, maize-wheat, and maize-pulses/ oilseed) of Uttar Pradesh during October to November and April to June. The samples were air-dried, gently ground, sieved through a 2-mm sieve and analysed for soil physico-chemical properties such as pH (Jackson 1973), soil texture (Gee and Bauder 1986), wet oxidisable carbon (Chan et al. 2001) and soil inorganic carbon (SIC) (Jackson 1973). The soil samples were further ground and passed through a 0.5 mm sieve for total soil carbon deter-

mination (CHN-O-RAPID analyzer (Anonymous 2006). The above ground and below ground biomass of residue crop (rice) was collected using Unconfined Destructive methods (Amos and Walters 2006) for parameterization of CENTURY model.

Carbon Analyses by Wet Oxidation and Dry Combustion

The wet oxidation method used in this study was the Walkley–Black procedure (Nelson and Sommers 1996), in which SOC is oxidized by potassium dichromate with sulfuric acid without external heating. A subsample of 1 g from a 2-mm sample of oven dried (40°C), sieved soil was placed in a 125 mL Erlenmeyer flask, and 10 mL of 0.2 M potassium dichromate solution was added. Then, 10 mL of concentrated sulfuric acid was slowly added to this solution. When the SOC content was >4%, larger volumes of potassium dichromate and sulfuric acid were used. Oxidation was performed at room temperature, and after a 30-min interval, 50 mL of distilled water, 3 mL of concentrated H₃PO₄ and four drops of the diphenylamine indicator were added. The SOC content after oxidation was determined by titration of the excess potassium dichromate using a 0.1 M solution of Mohr's salt. For each set of soil samples, three blank reagents were used to record the exact molarity of the Mohr's salt solution. Carbon content was determined using the following equation:

$$\text{g C kg}^{-1} = (\text{V}_b - \text{V}_s) \times \text{CFe}^{2+} \times 0.003 \times 1000 / \text{sample weight (g)}$$

where V_b and V_s are the volumes of Mohr's salt solution used for the titration of the blank and the soil sample, respectively; CFe²⁺ is the molarity of the Mohr's salt solution; 0.003 g mmol⁻¹ represents the ratio [(0.012)/4], where 0.012 is the molecular mass of C (g mmol⁻¹), and 4 refers to the number of electrons involved in the oxidation of OC. The dry combustion method was followed using an elemental analyzer (Anonymous 2006).

CENTURY Model Description

CENTURY (Parton et al. 1987) is a computer simulation model of plant-soil ecosystems that simulates the dynamics of C, N, P and S in different plant/soil systems through an annual cycle over years to millennia. Century has various submodeplant productivity, water movement and nitrogen leaching sub-models that determine the

turnover of nutrients within the system. Century allows the simulation of complex agricultural management systems including crop rotations, tillage practices, fertilization, irrigation, grazing and harvest methods. It uses a monthly time step utilising monthly average maximum and minimum temperatures and monthly precipitation data (Parton et al. 1987, Parton and Rasmussen 1994, Parton 1996). The grassland/crop and forest systems have different plant production sub-models that are linked to a common soil organic matter (SOM) and nutrient cycling sub-model (Parton et al. 1994). The plant litter material (aboveground and belowground) is split into structural and metabolic pools depending upon the lignin to nitrogen ratio and three SOM compartments, viz. active, slow and passive, which differ in their potential rates of SOM decomposition. The active pool (approximately 2% of total SOM pool) includes soil microbes and microbial products with short turnover times (1-3 months). The slow SOM pool (45-60% of total soil SOM) includes resistant plant material derived from structural plant material and stabilized soil microbial products that have turnover times ranging from 10 to 50 years depending on the climate. The passive pool (45 to 50% of total SOM) includes physically and chemically stabilized SOM that is very resistance to decomposition (turnover times from 400 to 4000 years). The structural decay rates to decrease as the lignin content increases (Parton et al. 1987), precipitation and soil texture.

CENTURY Model Evaluation Using Long Term Experiment

The CENTURY model was validated with the measured SOC obtained from a long term experiments. A long term experiment of rice–wheat cropping system (1988-2000) with treatment combinations of wheat straw (WS)+Urea-N (amount of added NPK: 176, 3.3, 61 kg ha⁻¹) (T4), WS+ green manure (GM)+Urea-N (amount of added NPK: 176, 3.3, 61 kg ha⁻¹) (T5) and farm yard manure (FYM)+GM (amount of added NPK: 186, 35, 81 kg ha⁻¹) (T7) was conducted at Ludhiana, Punjab of Indo-Gangetic Plain (IGP), India (30°54' N and 75°08' E, 247 m elevation, semi-arid subtropical with mean annual rainfall 800 mm, mean temperature 6.7-35°C) in the (Yadvinder-Singh et al. 2004). The maize–wheat rotation was followed for 20 years before the beginning of the experiment. The soil properties use for the model were pH_{1:2} 7.6, bulk density 1.50 g cm⁻³, clay 126 g kg⁻¹, silt 89 g kg⁻¹, sand 785 g kg⁻¹. Measured organic C 3.6 g kg⁻¹

was reported for depth 0–15 cm. Reported soil C data (0–15cm) were adjusted for comparison to the Century simulated depth of 20 cm by assuming a declining soil C value with depth and multiplying reported values by 1.17, the SOC at the depth 15–20 cm was assumed to have an amount approximately equal to 1/6 of the value found in the 0–15 cm sample (Bhattacharyya et al. 2007). These assumptions were based on data presented in Reddy et al. (2003) and Manna et al. (2006), where 1/3 of the mean of reported values for SOC found at depth 15–30 cm is equal to 1/6 of the mean of reported values in 0–15 cm.

RESULT AND DISCUSSION

Measured and Modelled Soil Organic Carbon (SOC)

Table 1 and Figure 1 show the comparison of measured SOC with modelled SOC over the same time period for each treatment in the two trials and the correlation coefficient (r). The modelling efficiency (ME) was computed from measured and simulated SOC using the equation given by Vereecken et al. (1991).

$$ME = 1 - \left(\frac{\sum_{j=1}^N (p_j - o_j)^2}{\sum_{j=1}^N (o_j - \bar{o}_j)^2} \right)$$

Where, p_j was the simulated values, o_j was the measured values, \bar{o}_j was the average of the measured values and N was the number of data pairs.

A modeling efficiency (ME) of 1 means perfect fit, while the positive value signifies closer fit (Foerid et al. 2007). The ME was 0.87, 0.93 and 0.97 for T4 (wheat straw (WS)+Urea-N), T5 (WS+ green manure (GM) + Urea-N) and T7 (FYM+GM) treatment trial respectively (Table 1). The r^2 are observed more than 0.9 for all the treatments in Ludhiana trial. In general, the model tended to overestimate with treatments. This overestimation could have been due to uncertainties in the history of land use (difficult to obtain historical details on native vegetation and land management after cultivation) and the subsequent effects on soil properties and also SOC analysis method adopted. The wet oxidisable method (Nelson and Sommers 1996) of SOC analysis might fails to give 100% recovery. Generic or “best guess” histories may lead to an overestimation or underestimation of initial soil C stocks (Bhattacharyya et al.

2007). This offset in initial C stocks influences the entire simulation of the experiment. This study is one of the few examples of Century being used to model SOC for different cropping patterns of Indo-Gangetic plains. Further investigation of the performance of Century is needed when modelling SOC turnover for different cropping pattern. Similar result was also reported by Bhattacharyya et al. (2007) that the CENTURY model simulation for treatment associated with organic matter was found overestimation approximately 15%. The CENTURY simulated SOC was very good fitting to the reported SOC for treatments and also consideration of the most recent data available. Overall, the CENTURY model appears to predict soil C and treatment effects relatively well.

Table 1. Comparison of CENTURY simulated and measured soil organic carbon (SOC) for different treatments effect in a long-term experiment of rice-wheat cropping system at Ludhiana (from Singh et al. 2004).

Treatments Year	Estimated SOC (g m ⁻²)	CENTURY-simulated SOC (g m ⁻²)	Model Efficiency	Correlation coefficient (r ²)
WS+urea-N (T4)				
1991	1035	1401.22	0.87	0.747
1993	1102.5	1445.16		
1995	1080	1490.18		
1997	1102.5	1534.29		
1999	1192.5	1577.12		
WS+GM+urea-N (T5)				
1991	1080	1409.23	0.93	0.957
1993	1170	1453.10		
1995	1215	1497.85		
1997	1237.5	1542.32		
1999	1327.5	1585.70		
FYM+GM (T7)				
1991	1215	1403.75	0.97	0.946
1993	1192.5	1447.54		
1995	1305	1492.21		
1997	1350	1536.61		
1999	1462.5	1579.93		

* WS = Wheat straw incorporated in situ, GM = 50–53-d-old *Sesbania cannabina* green manure, FYM = Farmyard manure applied at 5.8 Mg ha⁻¹ (dry weight basis).

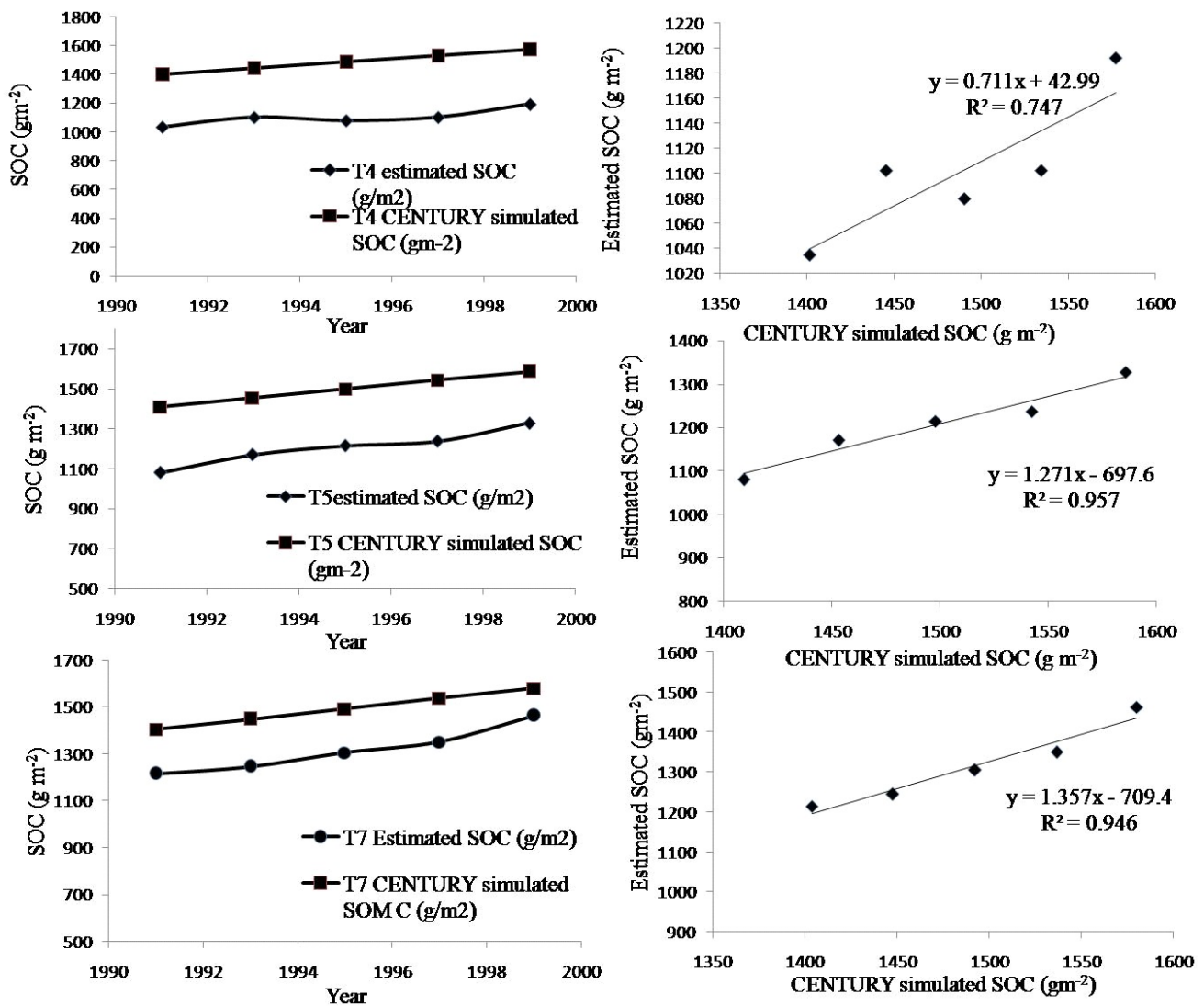


Figure 1. Comparison of CENTURY simulated and estimated soil organic carbon (SOC) for different treatments effect of Ludhiana trial (a long term experiment of rice-wheat system at Ludhiana). [Note: T4-WS+urea-N, T5-WS+GM+urea-N and T7-FYM+GM; WS-Wheat straw incorporated in situ, GM-50–53-d-old *Sesbania cannabina* green manure, FYM-Farmyard manure applied at 5.8 Mg ha⁻¹ (dry weight basis).

CENTURY Simulation of Soil Organic Carbon

The cropping patterns had influenced on SOC storage in the order of rice-wheat > sugarcane- wheat > maize-wheat > jowar-pulses/ oilseed (Table 2 and Figure 2). There was slowly decreased in SOC storage at initial for rice-wheat, sugarcane-wheat and jowar-wheat, later on sharp increased of SOC storage at these cropping systems with the addition of higher input. Similarly, the SOC storage for rich-wheat system (rotation) was found increasing trend up to 2030 (Bhattacharyya et al. 2007). Initially, there was single cropping sytem like rice-fallow, rice or maize/jowar-fallow, jowar-fallow and

converted to double cropping system such as rice-wheat, sugarcane- wheat, maize-wheat, and maize-pulses/ oilseed since green revolution start. More soil carbon was stored under rice-wheat system due to anearobic part under continuous flooded rice (rice-rice) and changing of monoculture to continuous crop rotation (Benbi and Brar 2009, West and Post 2002). The sugarcane-wheat system might be adding higher amount of crop residue. The sugarcane cropping system was followed for two years rotation with minimum tillage. The minimum soil tilth could enhance the SOC storage (Bhattacharyya et al. 2007, West and Post 2002). Organic matter decomposition increases with tillage by breaking up aggregates and

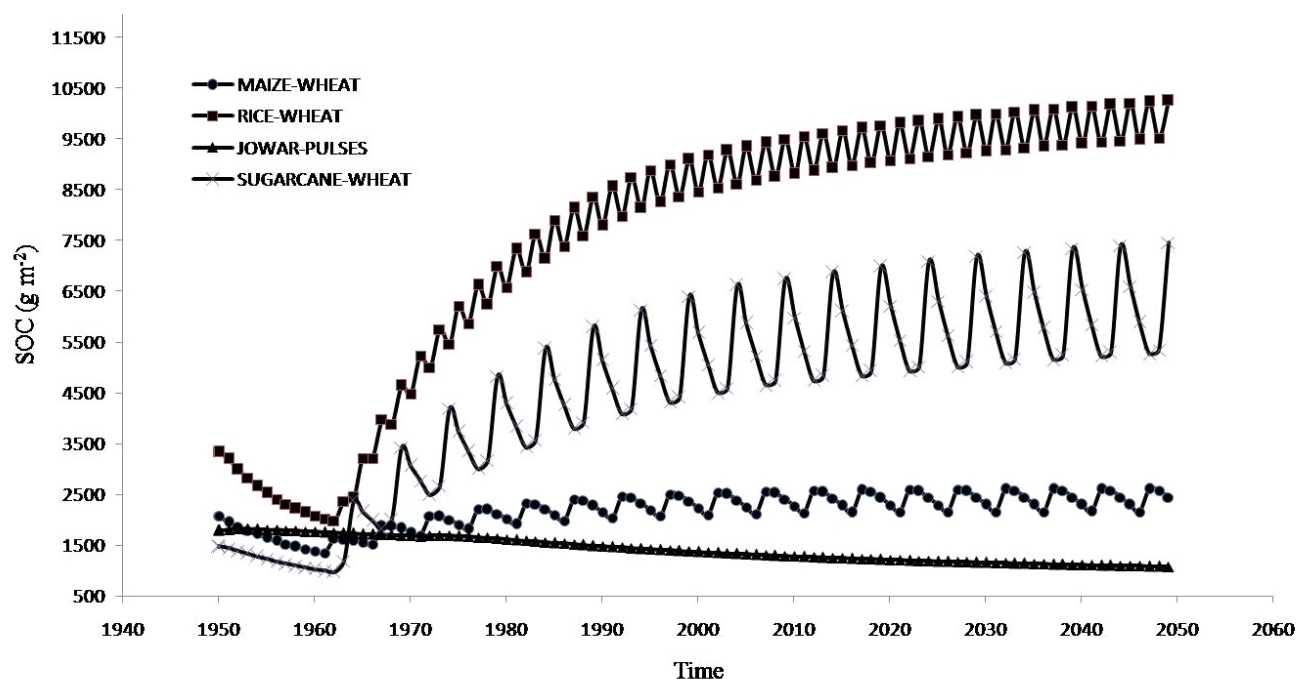


Figure 2. CENTURY simulated SOC (g m^{-2}) of different cropping pattern.

Table 2. The soil carbon storage for four dominant cropping patterns of Uttar Pradesh.

Land Use	SOC $\times 10^6$ (g ha^{-1})	
	0-15 cm	0-30 cm
Rice-wheat	25.25	45.17
Sugarcane-wheat	21.01	38.57
Maize-wheat	20.16	37.12
Maize-pulses/ Oilseed	7.56	14.14

more expose organo-mineral surfaces enhances microbial oxidation (Pretty et al. 2002). The increasing trend after 1995 was reduced and tending to attain towards equilibrium (Figure 2). Similar result was also reported by many scientists (Murty et al. 2002, Keeny et al. 2002). The jowar-pulses system was constantly declining the SOC storage (Figure 2). It seemed to be stabilised the SOC storage at jowar-pulses up to 1965. The jowar-pulses/ oilseed system was contributed the lower SOC storage as compare to other cropping systems since jowar-pulses/ oilseed system was grown at low soil moisture regimes areas and rapidly decomposed of residues of leguminous crop, low input and less above-

ground biomass (removed at the time of crop harvest). It was also reported that legume based cropping system was accumulated less soil carbon (Powlson and Olk 2000).

CONCLUSION

This study presents a preliminary attempt to parameterize the CENTURY model for different cropping patterns of Uttar Pradesh. The cropping patterns could significantly influence on SOC storage. Rice-wheat system would help in more SOC storage than that of other system. The longer duration of sugarcane crop might reduce the soil tillage practices. Thus the next highest SOC storage after rice-wheat system was recorded under sugarcane-wheat system at the similar agro-climatic condition. However, further adjustments may improve model performance at these sites.

ACKNOWLEDGEMENTS

We heartily extend our gratitude to Dr. Cinthia Keough, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523-1499, for providing

valuable suggestions and information for parameterization of CENTURY model.

REFERENCES

- Amos, B. and Walters, D.T. 2006. Maize root biomass and net rhizodeposited carbon: an analysis of the literature. *Soil Science Society of America Journal* 70: 1489-1503.
- Anonymous, 2005. Land Use Statistics. Ministry of Agriculture, New Delhi.
- Anonymous, 2006. CHN analyzer (model Foss Heraeus Elemental Analyzer CHN-O-RAPID, Manufacture Elementar Analysen System GmbH, Donaustasse 7, D-63452 Hanau, Germany.
- Batjes, N.H. 1996. Total carbon and nitrogen in the soils of the World. *European Journal of Soil Science* 47: 151-163.
- Benbi, D.K. and Brar, J.S. 2009. A 25 year record of carbon sequestration and soil properties in intensive agriculture. *Agronomy for Sustainable Development* 29: 257-265.
- Bhattacharyya, T.; Pal, D.K.; Easter, M.; Batjes, N.H.; Milne, E.; Gajbhiye, K.S.; Chandran, P.; Ray, S.K.; Mandal, C.; Paustian, K.; Williams, S.; Killian, K.; Coleman, K.; Falloon, P. and Powlson, D.S. 2007. Modelled soil organic carbon stocks and changes in the Indo-Gangetic Plains, India from 1980 to 2030. *Agriculture, Ecosystems and Environment* 122: 84-94.
- Bhattacharyya, T.; Pal, D.K.; Williams, S; Telpande, B.A.; Deshmukha, A.S.; Chandrana, P.; Ray, S.K.; Mandal, C.; Easter, M. and Paustian, K. 2010. Evaluating the Century C model using two long-term fertilizer trials representing humid and semi-arid sites from India. *Agriculture, Ecosystems and Environment* 139: 264-272.
- Blake, G.R. and Hartge, K.H. 1986. Bulk density. Pages 1-173, In: A. Klute (Editor) *Methods of Soil Analysis*. Part 1. (2nd edition). *Agronomy Monographs* 9. American Society of Agronomy and Soil Science Society America, Madison, WI.
- Chan, K.Y.; Bowman, A. and Oates, A. 2001. Oxidizable organic carbon fractions and soil quality changes in an oxi paleustalf under different pasture leys. *Soil Science* 166 (1): 61-67.
- Foereid, B.; Barthram, G.T. and Marriott, C.A. 2007. The CENTURY model failed to simulate soil organic matter development in acidic grassland. *Nutrient Cycling in Agroecosystems* 78: 143-153.
- Gee, G.W. and Bauder, J.W. 1986. Particle size analysis. Pages 1-1173, In: A. Klute (Editor) *Methods of Soil Analysis*. Part 1 (2nd edition). *Agronomy Monographs* 9. American Society of Agronomy and Soil Science Society America, Madison, WI.
- Houghton, R. A.; Skole, D. L.; Nobre, C. A.; Hackler, J. L.; Lawrence, K. T. and Chomentowski, W. H. 2000. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. *Nature* 403: 301-304.
- Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice-Hall of India, New Delhi. 452 pages.
- Keeny, E.A.; Hall, J.W. and Wang, C. 2002. Temporal trends in soil properties at a soil quality benchmark site in the lower Fraser valley, British Columbia. *Canadian Journal Soil Science* 82: 499-509.
- Lal, R. and Sanchez, P.A. 1992. *Myths and Science of Soils in the Tropics*. SSSA Special Publication No. 29. American Society of Agronomy, Madison, USA, Pp. 1-157.
- Manna, M.C.; Swarup, A.; Wanjari, R.H.; Singh, Y.V.; Ghosh, P.K.; Singh, K.N.; Tripathi, A.K. and Saha, M.N. 2006. Soil organic matter in a West Bengal Inceptisol after 30 years of multiple cropping and fertilization. *Soil Science Society of America Journal* 70: 121-129.
- Murty, D.; Krischbaum, M.U.F.; MxMurtie, R.E. and McGilvray, H. 2002. Does conversion of forest to agriculture land change soil carbon and nitrogen? A review of the literature. *Global Change Biology* 8: 105-123.
- Parton, W.J. 1996. The CENTURY model. Pages 283-293, In: Powlson, D.S.; Smith, P. and Smith, J.U. (Editors.), *Evaluation of Soil Organic Matter Models Using Existing Long-term Datasets*. NATO ASI Series I, vol. 38. Springer-Verlag, Heidelberg.
- Parton, W.J.; Schimel, D.S.; Cole, C.V. and Ojima, D.S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal* 51 (5): 1173-1179.
- Parton, W.J.; Schimel, D.S.; Ojima, D.S. and Cole, C.V. 1994. A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. Pages 147-167, In: Bryant, R.B. and Arnold, R.W. (Editors.) *Quantitative Modelling of Soil Farming Processes*. SSSA Special Publication 39, ASA, CSSA and SSA, Madison, Wisconsin, USA.
- Parton, W.J., Rasmussen, P.E., 1994. Long-term effects of crop management in wheat/fallow: II CENTURY model simulation. *Soil Science Society of America Journal* 58, 530-536.
- Poussart, J.N.; Ardö, J. and Olsson, L. 2004. Effects of data uncertainties on soil organic carbon in the Sudan. *Environmental Management* 33: S405-S415.
- Powlson, D.S. 2005. Will soil amplify climate change? *Nature*: 204-205.
- Powlson, D.S. and Oik, D.C. 2000. Long-term soil organic matter dynamics. Pages 49-63, In: Kirk, G.J.D. and Oik, D.C. (Editors) *Carbon and Nitrogen Dynamics in Flooded Soils*, Proceedings of the Workshop on Carbon and Nitrogen Dynamics in Flooded Soils. International Rice Research Institute, Los Banos.
- Pretty, J.N.; Ball, A.S.; Li, X.Y. and Ravindranath, N.H. 2002. The role of sustainable agriculture and renewable-resource management in reducing greenhouse-gas emissions and increasing sinks in China and India. *Philosophical Transactions of the Royal Society of London A* 360: 1741-1761.
- Pretty, J.; Noble, A.D.; Bossio, D.; Dixon, J.; Hine, R.E.; Penning de Vries, F.W.T. and Morison, J.I.L. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology* 40 (4): 1114-1119.
- Reddy, K.S.; Singh, M.; Tripathi, A.K.; Singh, M. and Saha, M.N. 2003. Changes in amount of organic and inorganic fractions of nitrogen in an Eutrochrept soil after long-term cropping with different fertilizer and organic manure inputs. *Journal of Plant Nutrition and Soil Science* 166: 232-238.

- Singh, N.J.; Kudrat, M.; Jain, K. and Pandey, K. 2011. Cropping pattern of Uttar Pradesh using IRS-P6 (AWiFS) data. *International Journal of Remote Sensing* 32: 4511-4526.
- Singh, S.P.; Ram, J.; Walia, C.S.; Sachdev, C.B.; Dhankar, R.P.; Rana, K.P.C.; Sehgal, J.; Velayutham, M. and Gajbhiye, K.S. 2004. Soils of Uttar Pradesh for optimizing land use. National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) Publication 68, Nagpur, India. 91 pages.
- Vereecken, H.; Jansen, E.J.; Hack-ten Broeke, M.J.D.; Swerts, M.; Engelke, R.; Fabrewitz, S. and Hansen, S. 1991. Comparison of simulation results of five nitrogen models using different datasets. Commission of European Communities Soil and Groundwater Research. Report II, Nitrate in soils. Luxembourg: Commission of the European Communities: 321-338.
- West, T.O. and Post, W.M. 2002. Soil Organic Carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Science Society of America Journal* 66: 1930-1946.
- Yadvinder-Singh; Bijay-Singh; Ladha, J.K.; Khind, C.S.; Gupta, R.K.; Meelu, O.P. and Pasuquin, E. 2004. Long-term effects of organic inputs on yield and soil fertility in the rice-wheat rotation. *Soil Science Society of America Journal* 68: 845-853.

*Received 5 April 2014;
Accepted 18 August 2014*