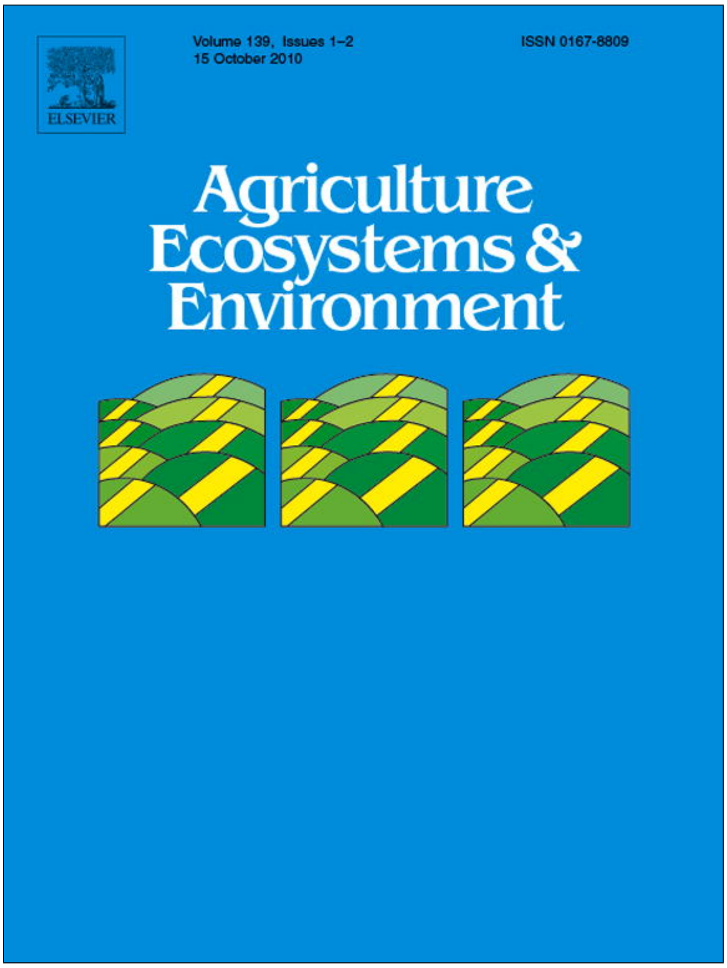
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Evaluating the Century C model using two long-term fertilizer trials representing humid and semi-arid sites from India

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ABSTRACT

Two long-term fertilizer experiments (LTFE) datasets were used to evaluate the performance of the Century ecosystem model in contrasting regions of India viz Mohanpur (humid) and Akola (semi-arid) with mean annual rainfall of 1619 mm and 793 mm, respectively. Mohanpur grew rice and wheat in rotation for 19 years since 1986. Akola grew sorghum and wheat in rotation for 9 years since 1988. Both these experiments involved treatments with different doses of inorganic (fertilizer) and organic (farm yard manure, paddy straw, and green manure) inputs. The model closely resembled measured SOC level for all the treatments in Mohanpur LTFE. For Akola, it tended to overestimate treatment effects at the end of the experimental period. At the humid site (Mohanpur) modelled data simulated measured data reasonably well for all treatments, with control and treatments with fertilizer alone and in combination with organic inputs showing the best agreement (RMSE 1–3). At the semi-arid site Century performed well for the early years, but lower during the end of the experiment. The comparison between measured and modelled yields for the three crops (rice, wheat and sorghum) showed a reasonably good correlation ($r = 0.8$).

1. Introduction

Long-term experimental studies have shown that soil organic carbon (SOC) is highly sensitive to changes in land use. There is always a loss of SOC when a native ecosystem such as forest is contrasted to agriculture (Jenkinson and Rayner, 1977). Cultivated land may result in an increase of SOC through reducing tillage and using cover crops (Bhattacharyya et al., 2004). Incorporating crop residues or increasing manure application also increase SOC (Bhattacharyya et al., 2000). Rates of land use change are greatest in the tropics where the demand for 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 or pastoral land, thereby releasing C from soils to the atmosphere (Batjes and Sombroek, 1997). Subsequent poor management of newly converted land can then lead to further losses of SOC and eventual degradation of land. Despite the importance of tropical areas in terms of the percentage of global SOC stocks and the vulnerability of these stocks (Batjes, 1996), we still have relatively little information about soils in these regions and how they react to land use/land management practices.

With the increasing realization that the management of the agricultural land is an integral part of a global carbon market, the need for soil carbon models to simulate agricultural cropping rotations is recognized. One such well-known model used to estimate carbon fluxes is Century (Parton et al., 1988). The Century model originally designed has most often been used to simulate soil organic matter decomposition under aerobic soil conditions. The model's frequent use in conjunction with long-term datasets to evaluate soil organic matter turnover has earlier been documented (Smith et al., 1996, 1997). One such effort with Century involved a 30 year dataset of jute–rice–wheat rotations in India (Bhattacharyya et al., 2007). More recently the Century model was applied to estimate SOC turnover in the aerobic–anaerobic soil conditions of rice systems in Prairie County, Arkansas (Milne et al., 2008) and Nepal (Shrestha et al., 2009). The Century model's capability for simulating soil carbon dynamics is a function of the detailed information on

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Table 1
Selected biophysical and management datasets for two long-term fertilizer trials in the IGP and BSR, India.

Site characteristics	Mohanpur[a]	Akola[b]
Location	Nadia, West Bengal	Akola, Maharashtra
Latitude/longitude	22°56′24.3′′ N, 88°31′81′′ E	20°57′04" N, 76°57′05′′ E
Site history	Perennial weeds and grasses	Deciduous and tropical woodland
Altitude (m)	9	247
Mean annual rainfall (mm)	1619	793
Temperature (MAT)	26.6	26.5
Experiment start year (duration)	1986 (19)	1988 (9)
Texture	Clay loam	Clay
Clay (%)	32.8	52.2
Silt (%)	49.4	21.7
Sand (%)	17.8	26.1
Bulk density (Mg m^{-3})	1.2	1.26[c]
pH	7.1	7.9
Organic C (%)	0.88 (1986)	0.46 (1988)
Site history	Perennial weeds and grasses	Deciduous and tropical woodland
Soil series (US classification)	Mohanpur (Vertic Endoaqualfs)	Akola (Typic Haplusterts)

[a] Source for Mohanpur: Ray et al. (2005), Majumder (2006) and Mandal et al. (2008).
[b] Source for Akola: Ravankar et al. (1998, 2004).
[c] Measured value.

site characteristics and experimental management practices, and, in as much detail possible, historical land use practices.

To evaluate the performance of the Century model, long-term fertilizer experimental (LTFE) data sets are required. These include soil organic carbon, soil texture, bulk density, crop yield and management practices. Many long-term fertilizer experimental datasets have been documented for Indo-Gangetic Plains (IGP) and black soil regions (BSR) in India (Swarup et al., 1998; Abrol et al., 2000; Bhattacharyya et al., 2005a). Out of these LTFE, two sites such as Akola, Maharashtra and Mohanpur, West Bengal were selected for the Century model evaluation. These two LTFE spots have contrasting climate (Akola: semi-arid climate; Mohanpur: humid), crop and crop management (Akola: sorghum–wheat, non-flooded; Mohanpur: rice–wheat, flooded rice) and quality and quantity of clay content (Akola: 52%, smectitic clay; Mohanpur: 33%, micaceous clay). Although the Century model has been evaluated to simulate soil organic carbon in a flooded rice system (Bhattacharyya et al., 2007; Milne et al., 2008), similar exercise is rare in soils containing pretty high clay dominated by smectitic mineral effecting very high cation exchange and water retention capacity of soils (Vertisols) (Soil Survey Staff, 2006).

We had made a humble effort to evaluate the performance of the Century model in two contrasting situations such as Akola and Mohanpur with special reference to differences in climate, crop, crop management and soil properties. For the present study, two sites, one each from IGP and BSR were selected for Century model evaluation. These two sites represent contrasting climatic zones, with Akola, Maharashtra, being in a semi-arid climate and Mohanpur, West Bengal, being in a humid area (Bhattacharyya et al., 2005a, 2008a,b). Ideally soil organic carbon turnover is dependent, among other factors, on soil moisture. The sites chosen for the present study are contrasting in view of flooded and non-flooded conditions. The model simulation exercise in these sites might also involve improvization of crop, event and site files to suit the requirements of site. The present study also aims this objective.

2. Materials and methods

The Century ecosystem model can simulate the dynamics of C, N, P and S in different plant or soil systems through an annual cycle over years to millennia. Century has various submodels (plant growth, water movement, nitrogen balance, etc.) that determine the turn over of nutrients within the system. The phosphorus and sulphur submodels were not used in this study. Century allows the simulation of complex agricultural management systems which include crop rotation, tillage practices, fertilization, irrigation, grazing and harvesting. The model uses a monthly time step utilizing average monthly maximum and minimum temperature and precipitation (Parton, 1996). The grassland/crop and forest systems have different plant production submodels that are linked to a common soil organic matter (SOM) and nutrient cycling sub-model (Parton and Rasmussen, 1994). This SOM consists of two forms of litter such as metabolic and structural. It also includes three SOM compartments referred to as active, slow and passive. These SOM compartments differ in their potential rates of SOM decomposition. Carbon leaves the active SOM component and is released either as CO_2 or moves into the slow SOM pool with the split governed by soil texture. The rate of transfer of SOM between slow and passive components is also regulated by soil texture.

2.1. Long-term fertilizer experiments (LTFE) at Mohanpur

The data sets from two LTFE sites were collected from published literature. The organic C in soils for both the trials are measured values. Selected biophysical and management related data are shown in Table 1.

The LTFE at Mohanpur, West Bengal was conducted over a 19 year period (1986–2004) (Fig. 1) (Majumder, 2006; Mandal et al., 2008). The experimental site was under paddy (monocrop) dependent on monsoon for a pretty long time before the experiment. The Mohanpur site represents a humid (mean annual rainfall, MAR ~1619 mm) climate with an average maximum and minimum temperature of 31.6 and 21.7 °C, respectively. In Century this was initially modelled as 7000-year equilibrium grass system (GITB). Before the start of the experiment, land use history of this part of India was modelled as a monocrop rice system completely dependent on monsoon rainfall. This rice was flooded during its entire growing period. This was forwarded by wheat under irrigated condition. During the experimental period two crops, rice and wheat were grown annually under varying nutrient and organic matter input and using mechanized cultivation. The detailed description of the experiment is given in Table 2.

Experimental soil carbon data were measured in Majumder et al. (2008). Mean monthly weather data (precipitation, maximum and minimum temperature) were used for the pre-experimental period and actual regional weather data was used for the experimental years.

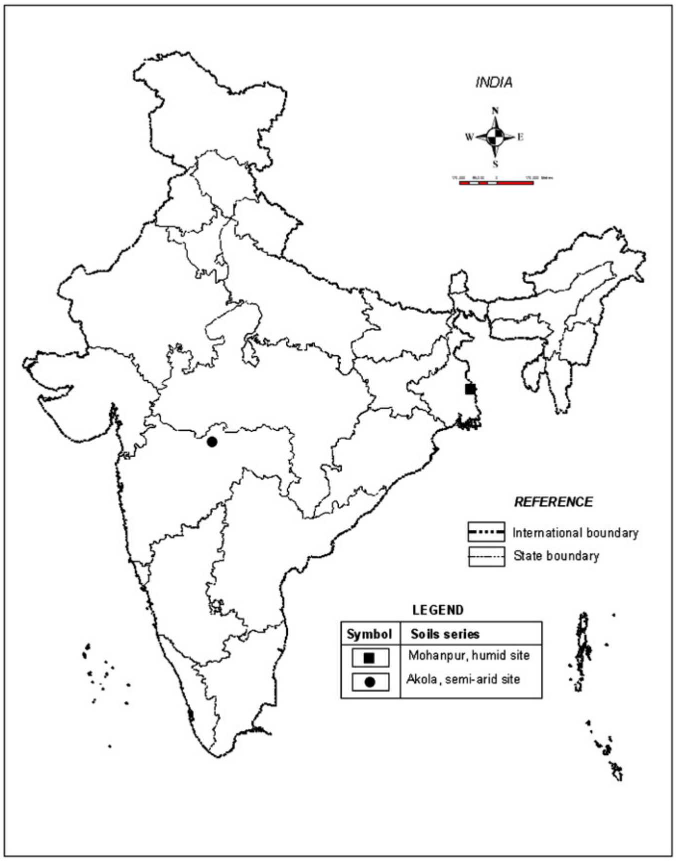

Fig. 1. Location of two long-term fertilizer trials representing humid and semi-arid sites in India.

2.2. Long-term fertilizer experiment (LTFE) at Akola

The Akola experiment was measured started in 1988 at Dr. Panjabrao Deshmukh Krishi Vidyapeth (University), Akola farm (Maharashtra, India) with sorghum–wheat cropping rotation (Ravankar et al., 1998, 2004). The soils are deep black soils (Vertisols: Typic Haplusterts) (Fig. 1) showing semi-aridic climate with MAR of 793 mm. Mean monthly maximum air temperature at this site ranges from 29.8 °C in January to 37.1 °C in June and minimum between 11.9 °C in January and 23.7 °C in July. The experiment includes different combinations of inorganic and organic nutrient sources (Table 2). For the present study we have undertaken to simulate treatments 1, 2, 13 and 14. Treatment 1 is control (no inorganic and organics) while T2 was the plot with 50% NPK. Treatments 13 and 14 were chosen to find out the influence of combination of inorganic and organic amendments (T13) over only organics (T14).

2.3. Regional crop and site information for parameterization of the Century model

It is known that the ability of the Century model to predict changes in SOC turnover depends largely on the plant productivity submodels to decide plant production in terms of crop yield and biomass and to determine amount of organic C returned to the soils. For the study areas the crops such as paddy, wheat and sorghum there are built-in submodels for these crops. Earlier exercise (Bhattacharyya et al., 2007) indicated that climatic parameters, their limits, management practices associated with these crop files are different as compared to the crops in the built-in crop files of the Century model (Table 3). Keeping in view the available datasets we have changed the modules of crop files we made earlier for the eastern part of the IGP for both rice and wheat (Bhattacharyya et al., 2007). Sorghum and wheat in the black soil regions of India were not used before for the Century model. We made changes to suit all these three crops to the tropical climate (Table 3) to use for specific BSR and IGP zones.

2.4. Model evaluation using Mohanpur and Akola sites

The Century model output was compared with field data to evaluate the performance of the Century model. Visual examination of graphic output allows qualitative evaluation. The measured and modelled datasets can be compared qualitatively through graphs and quantitatively by a number of statistical tests. In many cases a separate computer program called MODEVAL has been found to be effective for quantitative evaluation of model performance (Smith et al., 1996). While quantitative evaluation was performed using the MODEVAL which carries out a range of statistical tests designed to appraise the performance different models when compared to measured values (Smith et al., 1996). The statistical parameters selected are: the sample correlation coefficient (r), the coefficient of determination (CD) (which measures effectively the proportion of the total variance in the observed data, that is explained by predicted data), the root mean square error (RMSE) which is a measure of coincidence between measured and modelled values, M the mean difference between observations and simulations which gives indication of bias (or consistence error), and EF (modelling efficiency) which is modelling efficiency (Smith et al., 1996). Quantitative analysis was carried out for modelled vs. measured data for the period of 1986–2004 for Mohanpur and 1988–1997 for Akola in terms of soil C for both the models. The crop yield data modelled by Century was also compared with the measured yield of three crops.

Table 2
Experimental descriptions of the two trials used for model validation in the Indian IGP and BSR.

Crop rotation	Treatment number	N:P:K application (kg ha^{-1})
Mohanpur, West Bengal, India		
Rice–wheat	tr1	Control (No NPK and FYM)[a]
Rice–wheat	tr2	120:60:60
Rice–wheat	tr3	120:60:60 (for rice) and 100:60:40 (for wheat) + FYM
Rice–wheat	tr4	120:60:60 + PS (For rice and wheat)
Rice–wheat	tr5	120:60:60 + GM (For rice and wheat)
Akola, Maharashtra, India		
Sorghum–wheat	tr1	Control (No NPK and FYM)
Sorghum–wheat	tr2	50:25:20 (for sorghum) and 60:30:30 (for wheat) (50% NPK)
Sorghum–wheat	tr13	100:50:40 (for sorghum) and 120:60:60 (for wheat) + FYM (100%NPK + FYM at 10 t ha^{-1})
Sorghum– wheat	tr14	FYM (for sorghum and wheat) (FYM at 10 t ha^{-1})

[a] N, nitrogen; P, phosphorus; K, potassium; FYM, farm yard manure (C 7.5 t ha^{-1}); GM, green manure (C 8 t ha^{-1}); PS, paddy straw (C 10 t ha^{-1}). Source: Ray et al. (2005) and Ravankar et al. (1998, 2004).

Table 3
Crop files modified in the Century model for the IGP and BSR.

Rice			
Abbreviation	IGPRM[a]	IGPRM[b]	RICL[c]
Description	Rice monsoon	Rice monsoon	Low land rice
Sowing time	June–July	June–July	–
Duration (months)	5	5	5
Irrigation	Rainfed	Rainfed	Rainfed
PPDF (2)[d]	45	42	45

Wheat				
Abbreviation	IGPWE[a]	IGPWEM[e]	WW3S[c]	BSRW[f]
Description	Irrigated wheat eastern IGP	Irrigated wheat eastern IGP (Mohanpur)	Soft winter wheat high harvest index	Irrigated wheat black soil region
Sowing time	3rd week December	November		November
Duration (Months)	4–5	6	6	5
Irrigation	4–5	6	–	5
PRDX (1)[g]	300	325	450	475
PPDF (1)[h]	30	18	18	18
PPDF(2)[d]	35	35	33	40

Sorghum		
Abbreviation	BSRS[f]	SORG[c]
Description	Sorghum black soil region	Grain sorghum
Sowing time	June	June–July
Duration (months)	4	
Irrigation	–	
PRDX (1)[g]	375	680
PPDF (1)[h]	30	30
PPDF(2)[d]	45	45

[a] Please see Table 3 in Bhattacharyya et al. (2007).
[b] Modified for rice in this study.
[c] Original crop file Century.
[d] PPDF (2): maximum temperature for production for parameterization of Poisson density function curve to simulate temperature effect on growth.
[e] Modified for this study for IGP (Mohanpur); although wheat is grown during late December in eastern part of the IGP but the present experiment (our study area of Mohanpur) reports wheat sowing during November.
[f] Modified for the study of BSR (Akola).
[g] PRDX (1): potential aboveground monthly production for crops (g cm^{-2}).
[h] PDF (1): optimum temperature for production for parameterization of a Poisson density function curve to simulate temperature effect on growth.

3. Results

3.1. Modelled and measured soil organic carbon in Mohanpur trial

Figs. 2 and 3 show the measured and modelled SOC change rate through time for the Mohanpur and Akola trials, respectively. Tables 3 and 4 show quantitative statistical analysis of measured SOC with modelled SOC over the same time period for each treatment.

Fig. 4a–d shows the modelled and measured differences in treatment effects on 1:1 scale for the Mohanpur and Akola trials. The treatment effects indicate the differences between observed SOC for each treatment mean and the control within each experiment. For the Mohanpur trial which was carried out in humid climate, measured data for all the treatments, except the control showed an increase in soil carbon from 1986 to 2004 (Fig. 2a and b). In all cases the modelled output followed the trend of the actual data reasonably well as shown by greater than zero (0) correlation coefficient values for all the treatments (except the control) (Table 4). This shows a positive correlation between measured and modelled data. Interestingly for the control, measured data decreased slightly and then are levelled with the modelled data (Fig. 2a). This leads to a small negative correlation between measured and modelled data ($r = -0.27$, Table 4). Despite this the RMSE for the control was low (2.16) indicating that the differences between measured and modelled data were small. Accuracy of simulation is indicated by low RMSE (Smith et al., 1996).

In Mohanpur, RMSE was less than 3.5 for all the treatments, showing that the model was able to simulate actual datasets in all the cases. Treatment 3 (100% NPK + FYM) at the lowest RMSE (0.96) had a low *M* value, indicating bias (or consistent error) was less for this treatment (Table 4). Treatments tr2, tr4 and tr5 also had low RMSE and *M* values (tr4 had 0.16 *M*). All the treatments (tr2, tr3, tr4 and tr5) involved a combination of chemical (nitrogen) fertilizer and organic matter addition (farm yard manure, paddy straw and green manure). RMSE values were relatively high for treatment tr2 (only chemical fertilizer), tr5 and tr4. The lowest RMSE value in treatment tr3 suggests that Century works best for those conditions in Mohanpur when along with inorganic fertilizers organic amendments are applied through only FYM.

3.2. Modelled and measured soil organic carbon in Akola trial

The Akola trial was carried out in the semi-arid area of central part of India and involved a double crop sorghum–wheat rotation (Table 2). Overall, the Century modelled the Akola trial well in T1, T2 and T13. Treatment T14 with a negative correlation was an exception (Table 5). RMSE was lowest for treatment 1 (tr1) (1.74).

Treatment 2 and 13 (tr2 and tr13) had an RMSE of 39 and 18 showing relatively high *M* value for tr13. This indicates that bias or consistent error is affecting the way Century is modelling this particular treatment (tr13: 100% NPK + FYM). The Century model predicts soil carbon and the treatment effects (for inorganic fertilizer and organic amendments) well, but relatively better in the humid site than in the semi-arid site (Figs. 2–4). When all available data were considered together for these two trials, the model over predicted treatment effects by nearly 2–4% (Fig. 4a and b). When only the values during the earlier years at Akola (Fig. 4b) are considered the fit of Century's simulated treatment effects on soil carbon to measured treatment effects is good (Fig. 4d).

3.3. Measured and modelled crop yield

The Century model was parameterized using regional crop data from across the Indo-Gangetic Plains (IGP) (Bhattacharyya et al., 2007). A similar exercise has also been practised in semi-arid sites of India dominated by black soils (Vertisols). Figs. 5–7 show measured yield for the three crops (paddy, wheat and sorghum) grown in the two trials vs. modelled yield. The R^2 values of 0.64 shows a reasonably good association (Fig. 7).

4. Discussion

The evaluation of the Century model using the Mohanpur and the Akola long-term experimental trial gives as indication of the model performance at two sites contrasting in climate and soils (Fig. 1 and Tables 1 and 2). The Akola trial represents the very clayey cracking soils of the black soil region in the dry climate of the Deccan province. In contrast the Mohanpur site represents typical hydromorphic soils in the humid climate of eastern part of the Indo-Gangetic Plains of India (Fig. 1 and Table 1).

Century seems to model changes in SOC more successfully at Mohanpur site than at Akola site. The SOC levels were low to start

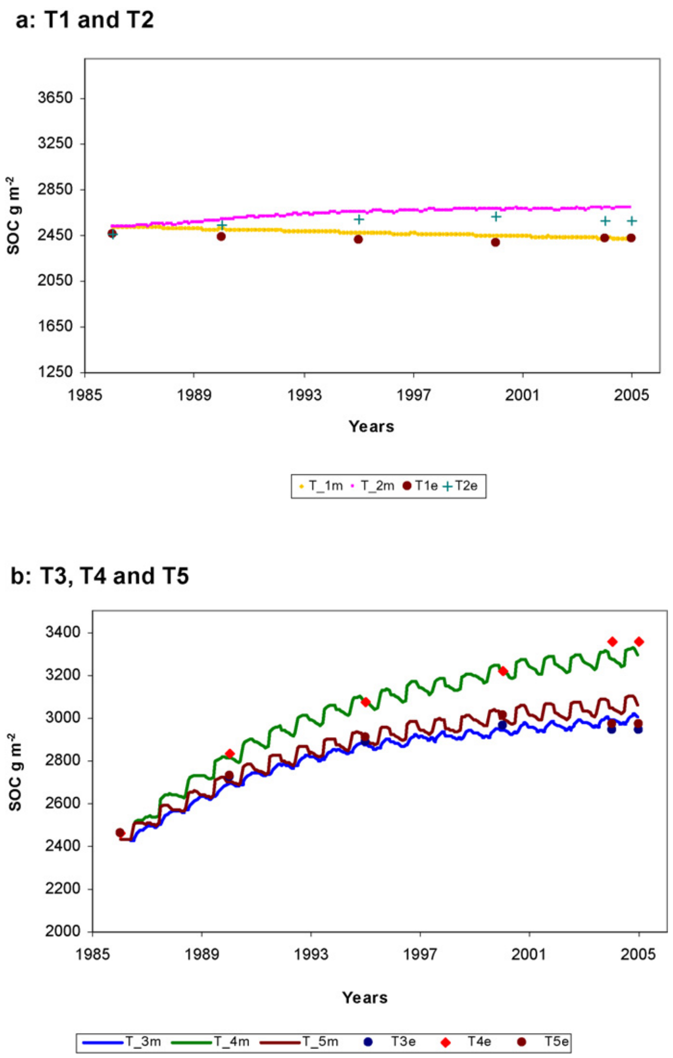

Fig. 2. Modelled and measured soil carbon over time for five management regimes included in the long-term fertilizer trial at Mohanpur, West Bengal (tr, treatment; m, model results; e, measured for 20 cm depth from measured data; T1, Control; T2, 100%NPK; T3, 100%NPK + FYM; T4, 100%NPK + PS and T5, 100% NPK + GM).

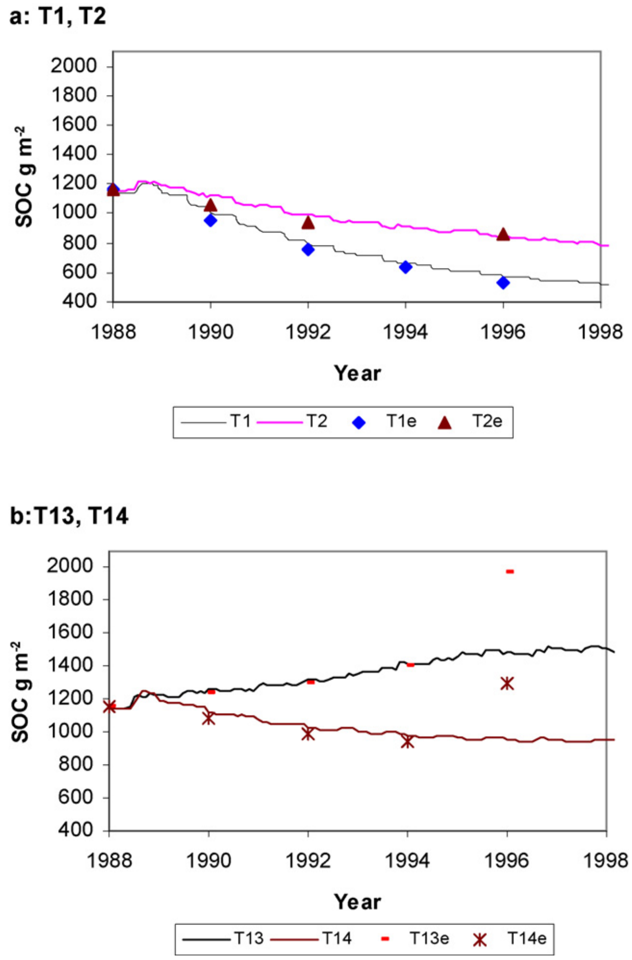

Fig. 3. Modelled and measured soil carbon over time for four management regimes included in the long-term fertilizer trial at Akola, Maharashtra. (T1 = Control, T2 = 50% NPK, T13 = 100% NPK + FYM and T14 = Only FYM).

with at Mohanpur and gradually showed the increasing trend when external inputs in the form of inorganic and organic manures are added.

For all the treatments at Mohanpur Century closely predicted measured SOC level for all the treatments with some exception of over estimation to the tune of 2–4%.

The Akola site, in contrast, did not provide historical details on native vegetation. Generic or 'best guess' histories prior to the start of Akola experiment might have under measured the soil carbon during the later part of the experimental period (Fig. 3a and b). This offset in the initial carbon status might have influenced the entire simulation process of the experiment. Measured SOC levels in treatments 13 and 14 at Akola exhibit a sharp increase (23–54%) during the later part of the experimental period. This pattern may indicate analytical differences between years that could be influencing the present analysis. Moreover, bulk density data are lacking throughout the experimental period in Akola (Ravankar et al., 1998, 2004). We therefore assumed bulk density value of 1.26 Mg m^{-3} to be constant for all times and treatments (Ravankar et al., 2004). For all treatments at Akola, Century results closely followed SOC treatment effects; however the model overestimates the SOC treatment effects at the end of experimental period. Analytical methods are not reported in the source material so it is possible that, these analytical techniques for measuring organic carbon in soils may have differed between earlier and later years.

Earlier experience of evaluation of Century model in the IGP, India showed overestimation by Century at the humid site (Bhattacharyya et al., 2007). This study evaluated Century which involved a rice–wheat–jute rotation in which rice was grown under submerged conditions for more than 5 months in a year for the experimental period of 30 years. More recently Milne et al. (2008) suggested that Century may be less suited to estimate carbon dynamics of soils under rice flooded every year. In contrast, the present study at Mohanpur, flooded rice (flooded for 6 months over a period of 19 years of experimentation) (rice–wheat rotation) yielded a good Century output from the humid bio-climatic system. So far as BSR is concerned the present study is perhaps the first of its kind to evaluate the model in a site represented by cracking clay soils with nearly 50% clay in the surface layer. It appears that further development of Century model is needed to improve performance when modelling carbon return to the soil under extremely clayey soils as in Akola. In the present study under almost similar situations with difference in soil properties (Table 1) Century performance is much better. This is pertinent, given the fact that wheat has been a common crop at both the sites.

Modelled vs. measured average crop yields for three major crops (rice, wheat and sorghum) are shown in Figs. 5–7. Yield averages for 19 years at Mohanpur (1986–2004) and 9 years (1988–1997) at Akola. The yield values for Akola site (Ravankar et al., 1998, 2004) and those for Mohanpur were collected (personal communication,

Table 4
Quantitative statistical analysis of modelled (Century) vs. measured soil organic carbon data for Mohanpur in the IGP[a].

Statistic[b]	Treatments				
	tr1Control (No NPK and FYM)	tr2 (100N)	tr3 (100N + FYM)	tr4 (100N + PS)	tr5 (100N + GM)
r	−0.27	0.91	0.99	0.99	0.99
RMSE (%)	2.16	3.34	0.96	1.43	1.70
EF	−3.64	−1.97	0.98	0.98	0.94
CD	0.183	0.240	0.86	1.18	0.80
M	−0.44	−0.82	−0.03	0.16	−0.31

[a] Statistical analysis carried out using MODEVAL (Smith et al., 1997). In all cases $n = 6$, Treatments: N, nitrogen fertilizer (t ha^{-1}); P, phosphorus fertilizer (t ha^{-1}); K, potassium fertilizer (t ha^{-1}); FYM, farm yard manure; PS, paddy straw; GM, green manure.
[b] *r*, correlation coefficient; RMSE, root mean square error of model; EF, modelling efficiency; CD, coefficient of determination (best fit = 1); *M*, mean difference.

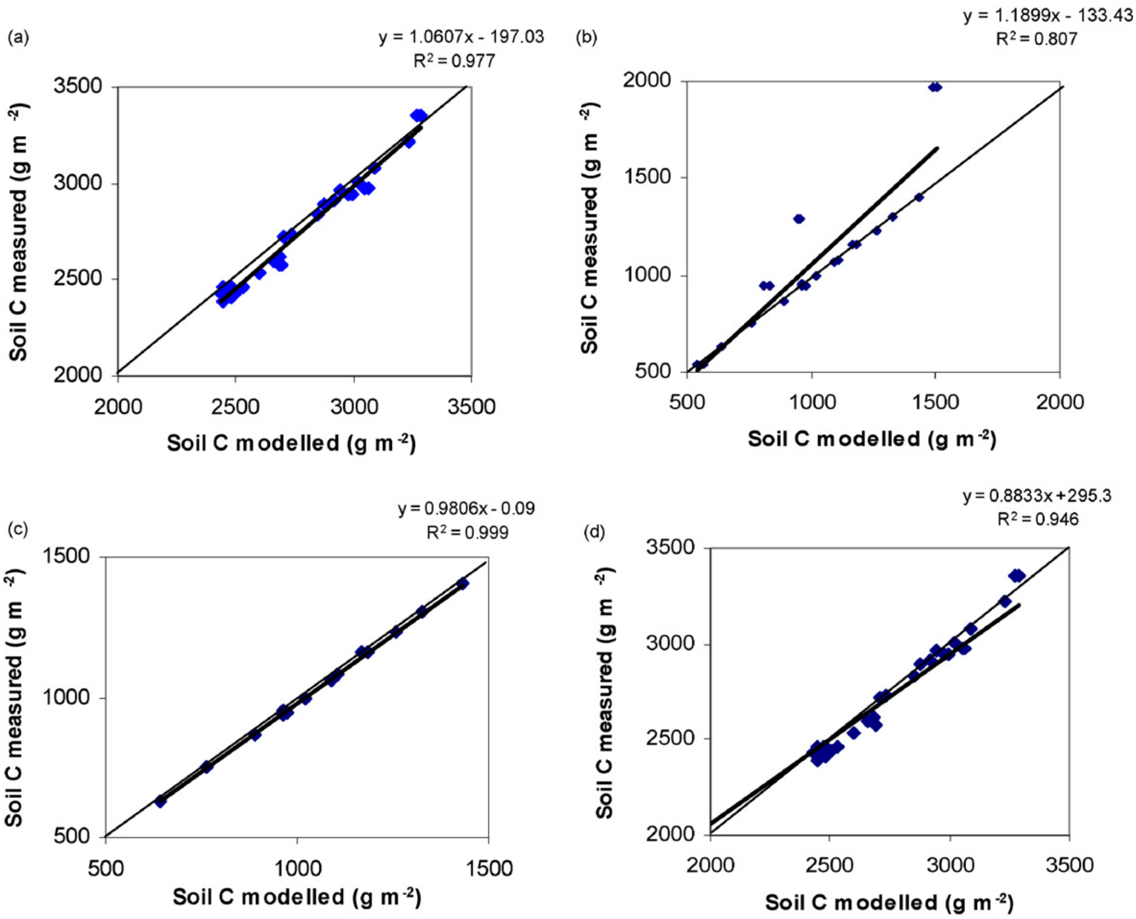

Fig. 4. (a) Differences in treatment effects (modelled vs. measured) for the Mohanpur trial during experimental period (1986–2004). (b) Differences in treatment effects (modelled vs. measured) for the Akola trial during experimental period (1988–1997). (c) Same for Akola for the datasets of earlier years only (1988–1994). (d) Combined datasets for both the trials to show differences in treatment effects (modelled vs. measured) (1988–1997).

Table 5
Quantitative statistical analysis of modelled (Century) vs. measured soil organic carbon data for Akola in the BSR[a].

Statistic[b]	Treatments			
	tr1 Control (No NPK and FYM)	tr2 (50% NPK)	tr13 (100%NPK + FYM at 10 t ha^{-1})	tr14 (FYM at 10 t ha^{-1})
r	0.997	0.86	0.90	−0.19
RMSE (%)	1.74	39.05	18.01	17.58
EF	0.997	0.39	0.34	−1.20
CD	1.01	0.49	3.31	1.06
M	−0.11	0.25	1.40	0.97

[a] Statistical analysis carried out using MODEVAL (Smith et al., 1997). In all cases $n = 6$, Treatments: N, nitrogen fertilizer (t ha^{-1}); P, phosphorus fertilizer (t ha^{-1}); K, potassium fertilizer (t ha^{-1}); FYM, farm yard manure.
[b] *r*, correlation coefficient; RMSE, root mean square error of model; EF, modelling efficiency; CD, coefficient of determination (best fit = 1); *M*, mean difference.

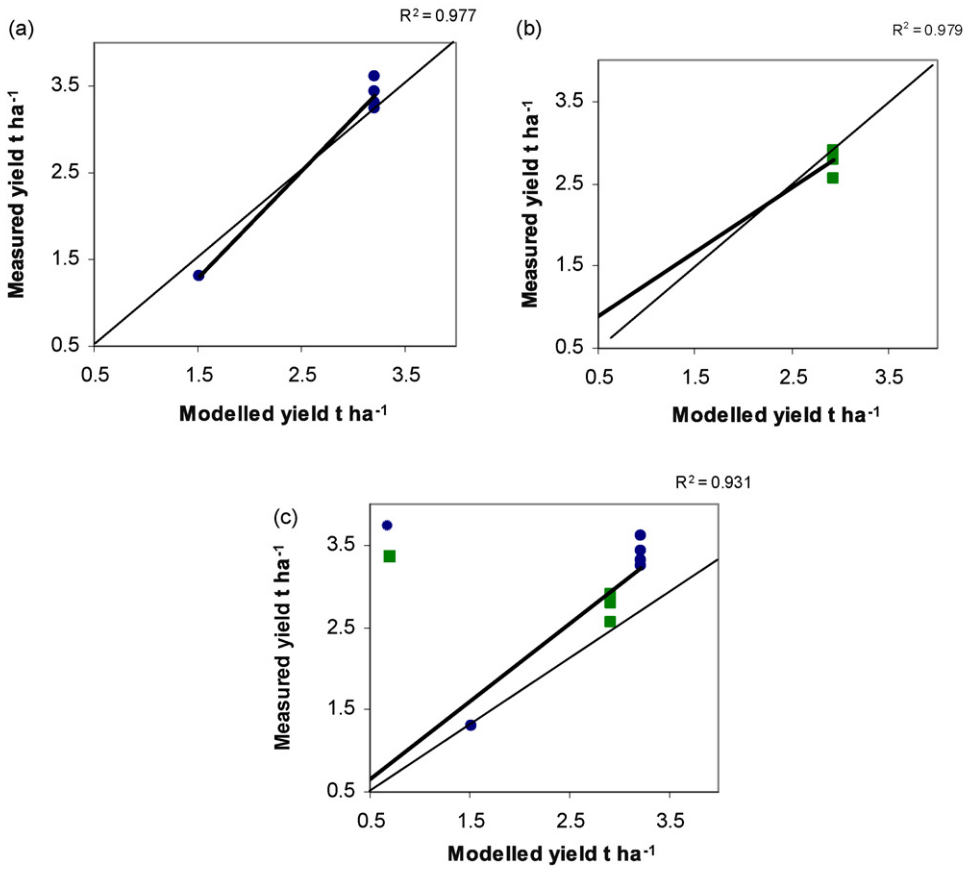

Fig. 5. Modelled vs. measured yield from Century model in humid site of the Mohanpur experimental spot: (a) rice, (b) wheat and (c) for both rice and wheat.

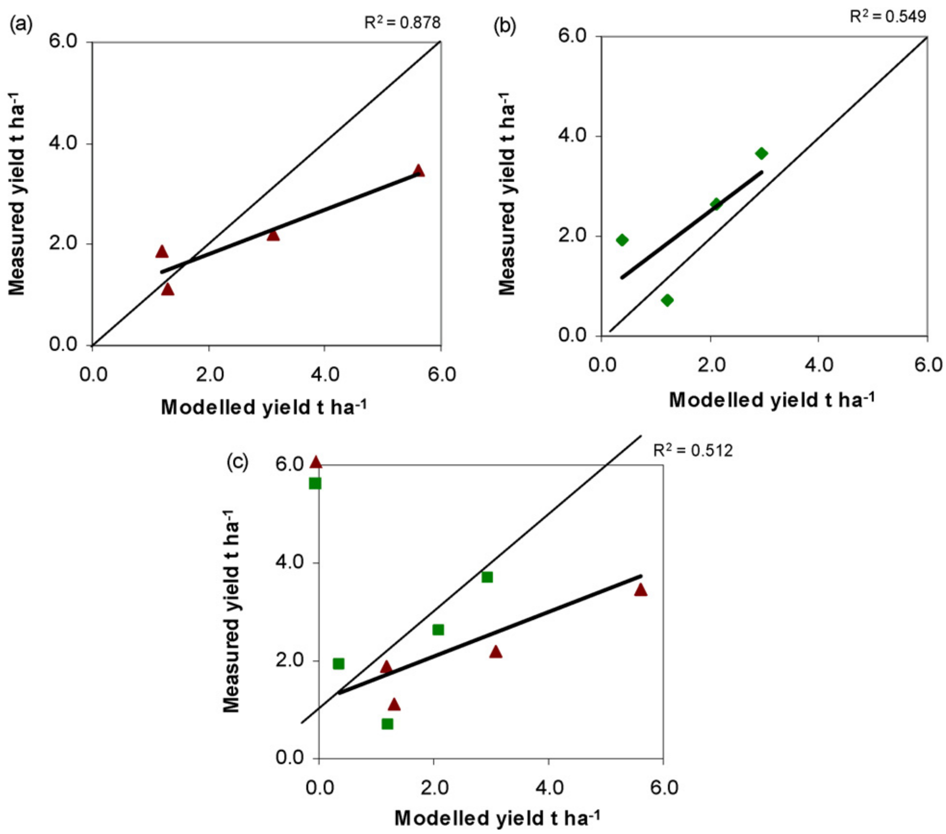

Fig. 6. Modelled vs. measured yield from Century model in semi-arid site of the Akola experimental spots: (a) sorghum, (b) wheat, (c) and both sorghum and wheat.

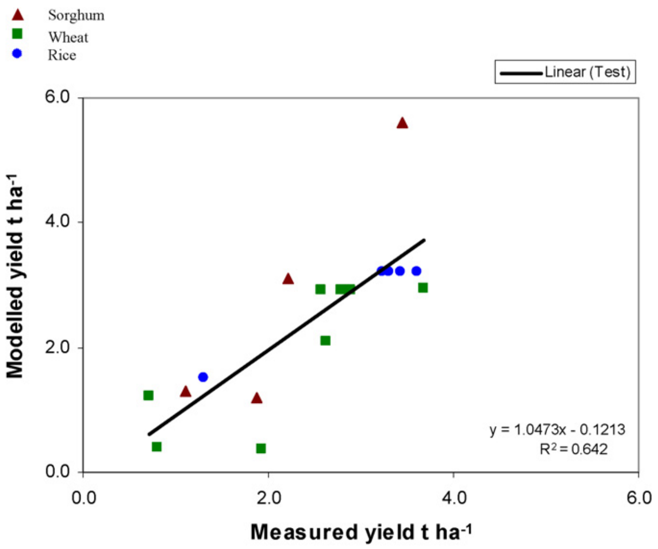

Fig. 7. Modelled vs. measured yield from the Century model for two long-term fertilizer trials in India.

B. Mandal). In general Century appeared to simulate production reasonably well for all the three crops. Comparison of individual crop yields are shown in Figs. 5 and 6. When all three crops were considered together, the correlation coefficient was 0.81.

The crop files obtained along with the Century model are generally parameterized with data collected from the temperate regions of North America. The authors felt it best to gather data that will enable them to build crop files with more suitable production parameters and residue-to-yield relationships for the different crop varieties grown in their areas (Table 3). Similar exercise was carried out earlier in the IGP and regional rice and wheat crop modules were developed. Detailed datasets on climatic constants, sowing time, irrigation, fertilizers, manures and method of harvesting permitted to build separate crop files for wheat and rice in different season as well as zones within the IGP (Bhattacharyya et al., 2007). With the proper relationships Century simulation of measured yields is a gauge of the model's performance in replicating actual crop residue returns of carbon and nitrogen to the soil and in replicating crop–water relations. The modified crop files for Mohanpur (IGP) brought better results (Fig. 2a and b); however, for Akola (BSR) the plots receiving FYM (with and without inorganic fertilizers) did not produce a good match between measured and modelled values of SOC and yield.

5. Conclusion

This study presents an attempt to parameterize the Century model crop files, management event files and site files for application to rice–wheat and sorghum–wheat cropping systems in two contrasting climatic and substrate (soil) conditions. The study indicates that Century can simulate the treatment effects in the different bio-climatic systems in terms of predicting SOC change. The model is more successful when applied to a humid climate represented by alluvial soils of the IGP than the vertisols and semi-arid climate of the BSR.

Century was calibrated to simulate crop yields for the two sites using data from IGP and BSR. The availability of more long-term experimental datasets for testing and validation is critical to the application of the model's predictive capabilities for this area in the Indian sub continent. This should be with special reference to very clayey cracking soils of the black soil region. Century does not model deep and wide cracks of these soils which are developed during dry days and remain active for more than 4–5 months in a year. This effect on plant available water is therefore missing from our simulations. Model simulations also assume the plant nutrients other than nitrogen are in adequate supply. While this assumption may generally reflect our site conditions, temporal variations in nutrient availability could be reflected in measured yields. More datasets will be necessary on soil–clay–moisture relation vis-à-vis the availability of moisture in these Vetisols for refinement of model simulations.

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