Project Update

July 1, 2005 - June 30, 2006

for

Carbon Sequestration in Soils of the Rice-Wheat Cropping System

Submitted to the Soil Management CRSP Management Entity
University of Hawaii

by

Cornell University

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I. Objective 1. Develop practical methods to measure gains and losses of soil organic C over time in spatially variable soils

1. <u>Development of Soil C-Texture Relationships</u>

Carbon measurement issues

Our previous annual reports have noted that Graham's colorimetric procedure gives the best agreement with Cornell's combustion results; and our Nepali colleagues are now utilizing this method as a standard operating procedure in the NARC Soils Lab. A graduate student at IAAS is also using the colorimetric procedure for analyzing soil samples for his Master's thesis.

The loss on ignition (LOI) protocol was introduced last year as an easier and less expensive method than the colorimetric procedure for Nepali soils labs. However hands on experience with LOI in Nepal has been mixed. NARC Soils Lab used colorimetric TOC results to calibrate LOI for 195 soil samples from the Chitwan district (Figure 1). As expected the regression coefficients are different from those we developed using LOI and combustion data (TOC = 0.453(LOI)-0.095), but also the correlation between LOI and colorimetric values (r^2 = 0.63) was not as good as between LOI and combustion (r^2 = 0.92). It is possible that irregular power supply and humidity played a role in the observed variability.

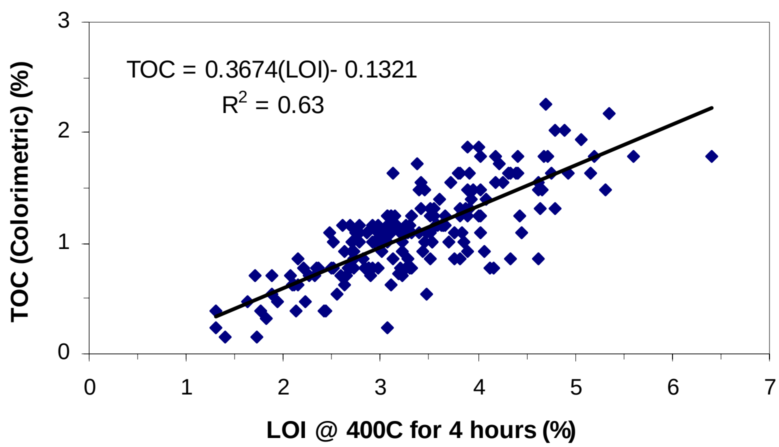

Figure 1. Loss on ignition calibration with TOC by the colorimetric procedure

The IAAS graduate student also used LOI on soils collected from the zero tillage experiment at Baireni, Chitwan. He calibrated LOI with combustion data from Cornell. In this case, there was excellent correlation between LOI and combustion data (r = 0.95); however, the regression coefficients were substantially higher than we had found (TOC = 0.796(LOI)-4.09). Losses after heating tended to be twice as high as our losses on similar soils, suggesting that the muffle furnace temperature was higher than thought. At IAAS it was impossible to check whether the actual oven temperature agreed with the dial setting. A muffle furnace with digital control is needed for LOI to be successful; otherwise, new calibrations are required for each lab oven.

Soil carbon-texture relationships

<u>Native and Rice Wheat Sites</u>:

Additional data for native forest sites (Bangladesh and Nepal) and other no-tillage systems (tea garden and mango orchard in Nepal) were obtained in PY 9, mostly to a depth of 60 cm. We now have a total of 99 sites. The data for these sites showed considerable variation (Figure 2 upper panel) for 0-15 cm soil depth. Possible reasons for this variability are:

- Forest sites are disturbed in that they are used for harvesting wood and forage materials and may be grazed; consequently reducing C inputs and lowering SOC levels.
- Flooding and erosion are continually modifying forest sites in the Nepal terai
- The land use history of the forest sites is not always well known so SOC levels may be lower than the equilibrium levels.

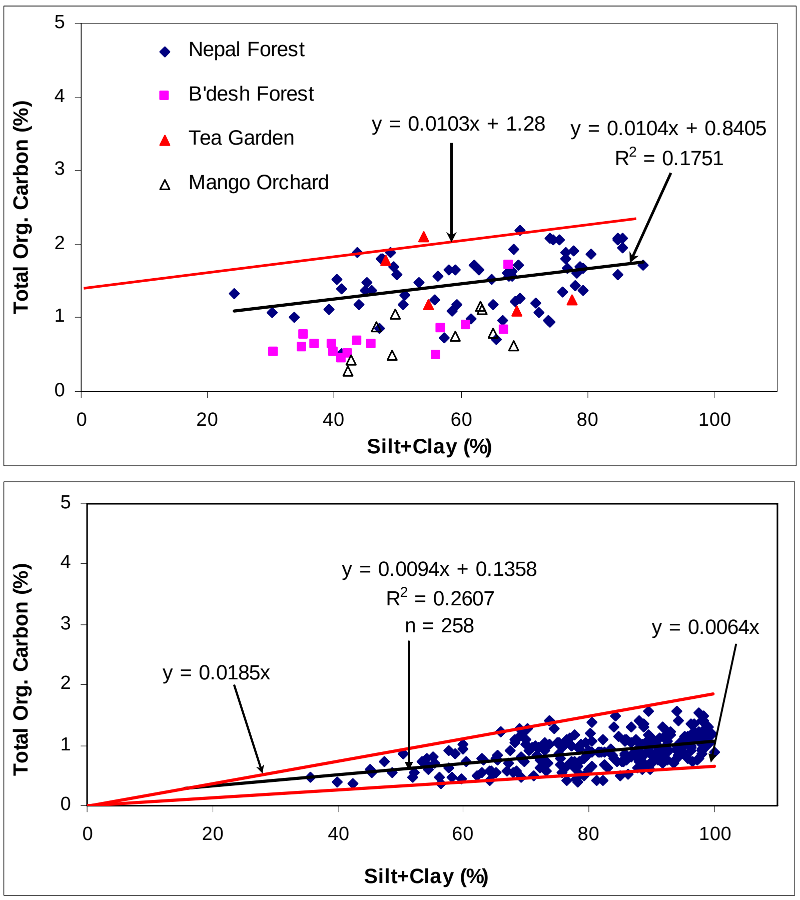

Figure 2. Soil organic C and texture relationship for the 0-15 cm depth for native forest and managed tree sites (upper) and rice-wheat sites (lower)

The data for both rice-wheat sites (Figure 2, lower panel) and the “native” ecosystem sites give an indication of the variability that exists in SOC content for surface soils and highlight the difficulty of finding sites that are truly representative of a long-term natural forest. We believe that it is justifiable to take an empirical approach to establishing relationships between SOC and silt + clay content to define maximum and minimum SOC levels from the SOC survey data and to use these to help interpret results from the modeling work described under Objective 2. Accordingly, regressions for maximum and minimum values, as appropriate, are shown in figure 2.

2. Characterization of Organic Carbon Gains from Sequestration Practices

Long-term Soil Fertility Experiments in Nepal Terai

Carbon stocks in 3 long-term soil fertility experiments at Bhairahawa, Parwanipur and Tarahara and at adjacent grassland sites (except Tarahara) were measured 25 years after their start. The cropping systems were triple crop rice-rice-wheat at Bhairahwa and double crop rice-wheat at the other sites. All experiments were started in 1978 with similar core treatments (table 1). There was no return of straw residues to the experiments, except for one treatment at Parwanipur where wheat straw (10 t/ha) plus 50 kg N/ha was added to rice. An additional treatment where NPK was added to the wheat crop and FYM + 50 kg N/ha to the rice crop was also included at Parwanipur.

Table 1. Treatments and nutrient inputs (kg/ha) in the long-term rice-rice-wheat experiment at Bhairahawa, and rice-wheat experiments at Parwanipur and Tarahara

Treatment	**Rice**[1]			**Wheat**		
	N	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
Unfertilized	0	0	0	0	0	0
NPK	100	30	30	100	40[2]	30
FYM	10 t/ha (wet wt)			10t/ha (wet wt)		
FYM/NPK[3]	10 t/ha FYM + 50-0-0			100	30	30
Straw/NPK[3]	10 t/ha straw + 50-0-0			100	30	30

[1] for both rice crops at Bhairahawa
[2] 30 at Parwanipur
[3] only at Parwanipur

At Bhairahawa and Parwanipur, areas directly adjacent to the experiment were maintained as unfertilized grassland since the inception of the experiment; this had been part of the field where the experiment was placed and it represents a conversion to no-tillage. The grass was more or less continuously harvested for animal feed so residue inputs were largely through the root system.

Mean crop yield data for the three experiments are shown in Table 2. Yields of all crops for the FYM and NPK treatments were generally similar at Bhairahawa and Tarahara. Lower crop yields for the FYM treatment compared to the NPK treatment at Parwanipur suggest an N limitation with the FYM treatment, which is supported by the higher crop yields in the FYM/NPK treatment. However, yield differences, unless extreme, are unlikely to lead to differences in root inputs of C to soil. Root inputs are most relevant to soil C stocks since above-ground biomass was removed from the fields (except for one treatment at Parwanipur). The removal of straw is similar to farmer practice.

Table 2. Mean grain and straw yields for long-term soil fertility experiments

Site/Treatment	Early Rice Yield (t/ha)		Main Rice Yield (t/ha)		Wheat Yield (t/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
Bhairahawa						
Unfertilized	0.40	NM[1]	1.07	1.67	0.53	NM
NPK	2.76		3.08		2.30	
FYM	2.80		3.14		2.20	
Tarahara						
Unfertilized	3.02	4.48	NA	NA	1.28	1.88
NPK	3.84	7.07			3.31	3.84
FYM	4.03	7.01			2.23	2.75
Parwanipur						
Unfertilized	1.96	3.08	NA	NA	0.64	0.76
NPK	3.16	5.46			2.04	2.52
FYM	2.67	4.37			1.14	1.52
FYM/NPK	3.32	5.72			2.15	2.63
Straw/NPK	3.00	5.32			2.03	2.66

[1]NM = not measured

Soils were sampled in 15 cm increments to a depth of 60 cm and bulk density of each depth increment was determined. Organic C and N were determined by dry combustion using a Europa Roboprep C and N analyzer. Pre-weighed samples of soils from Bhairahawa were treated with acid to remove $CaCO_3$ prior to analysis; this was not necessary at the other two sites. As expected, carbon stocks (Table 3) were highest in the FYM treatment and lowest in the unfertilized treatment. Some observations from the carbon stocks data are:

Table 3. Carbon stocks (0-60 cm) in long-term soil fertility experiments

Treatment	Total Organic C in 0-60 cm (t C/ha)		
	Bhairhawa	Parwanipur	Tarahara
Unfertilized	31.9	23.1	37.3
NPK	37.5	24.8	37.5
NPK (wht), 0.5N + Straw (rice)	-	28.4	-
NPK (wht), FYM + 0.5N (rice)	-	27.7	-
FYM	53.1	33.4	48.3
Unfert. Grassland	52.6	31.3	

- Soil carbon stocks in the unfertilized and NPK treatments were similar at Parwanipur and Tarahara despite large differences in above ground biomass production (Table 3). This indicates that residue inputs (almost all through roots) were the same in the two treatments. At Bhairahawa, a strong P deficiency developed in the unfertilized treatment after 6 years, which in combination with N deficiency, severely limited plant growth and clearly reduced root growth and residue inputs compared to the NPK treatment.

- Soil carbon stocks increased substantially in the FYM treatment at all three sites.
- Soil C stock increases in the FYM treatment were essentially equaled by the unfertilized grassland at both Bhairahawa and Parwanipur indicating that changing to no-tillage was equivalent to adding 10t/ha fresh manure (estimated to contain 1.8 t C/ha) per crop.
- Between 43-60% of the soil C stock (0-60 cm) was found in the top 15 cm of soil.
- Treatment effects were restricted to the 30 cm depth at Bhairahawa and to the 15cm depth at the other sites.
- The pattern of the results is strikingly similar to those from the Broadbalk long-term small grain (wheat and barley) experiments at Rothamsted, England which have run for 160 years with a single crop per year. Time is effectively accelerated in the Nepal terai with the double or triple cropping systems, a much warmer climate and irrigation of crops.

Permanent Bed Experiments

Our research has shown that permanent raised beds are a viable option for rice-wheat systems, leading to both increased crop yields and increased use efficiency of inputs (water and N). They also are close to a zero tillage option and so should increase soil C stocks. Carbon stocks were measured in two experiments, one at Nasipur in Bangladesh and the other at Ranighat in Nepal, after they had been in place for 4 years. Details of the experiments, which also include conventional practice treatments for comparison, can be found in our earlier reports.

Measurement of soil C stocks in the beds is complicated by the land surface structure created by the beds. We sampled both bed and furrow regions of the beds. We used a strategy that should collect samples to the same soil depth. Samples were collected in 5 cm increments to a depth of 15 cm, then from 15-35 cm on the bed, 15-25 cm in the furrow and 15-30 cm in the conventional, flat treatment. Sampling was by a Giddings soil corer (5 cm diameter) in Bangladesh and by hand in Nepal (2.5 cm diameter). Care was taken not to compact soil so that each sample also provided a bulk density value. The cumulative mass of soil and soil C collected in the whole column was determined. A weighted average was obtained for the permanent bed based on the dimensions of the bed and the furrow; 66.7% of the plot area was assigned to the bed and 33% to the furrow. The values for total soil mass were very close (< 10%) with slightly more soil being collected from the permanent beds. Soil carbon stocks were equalized to the same mass of soil by adding increments to the conventional treatments; these were calculated from the difference in soil mass and the C content of the lowest depth increment collected. The same approach was used at the Nepal site, except that sampling was to 50 cm. The sampling strategy, together with % soil C values in the different depth increments is shown for the Bangladesh experiment in Figure 3.

The total organic C stock for the nominal 0-30 cm depth was 26.88 and 23.78 t C/ha for the permanent beds and conventional practice, respectively, with the values significantly different at $p < 0.001$. The annual rate of soil carbon accumulation in this experiment is 0.78 t C/ha, which is at the high end of the range reported for no-tillage soils. Data from the Ranighat, Nepal experiment show the opposite trend and we are working to resolve some potential problems with the data set.

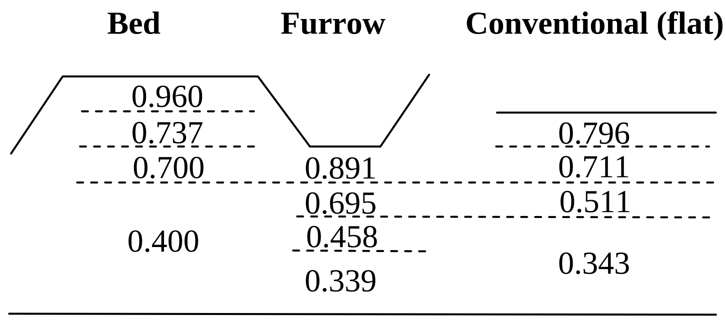

Figure 3. Schematic of physical arrangement and sampling scheme for permanent bed and conventional (flat) management at Nashipur Bangladesh , showing measured % OC values

Continuing tillage experiments

Tillage experiments continuing for sampling in the last year of the project are:

- tillage and crop establishment at Bhairahawa, Nepal
- crop residue management at Bhairahawa, Nepal
- surface seeding no-till and conventional till experiments at
  - IAAS, Rampur, Nepal
  - Baireni, Nepal
- permanent bed experiments at:
  - Nashipur, Bangladesh
  - Ranighat, Nepal

Except for the crop residue experiment, all of these experiments have combinations of mulch and tillage treatments.

II. Objective 2. Apply methods to assess the potential for carbon sequestration for selected sites in South Asia

1. Modeling of Carbon Dynamics in Long-term Soil Fertility Experiments

Our ultimate goal is to use models to project the impact of management changes in the rice-wheat system on soil carbon stocks. In PY 9, modeling of the long-term soil fertility experiments was undertaken with both the Century and RothC soil carbon models. Neither model has been used for rice wheat systems, except for a preliminary study by the Coloroado State NREL Century modeling group. Century has provision for anaerobic environments and tillage variables but Roth C does not.

Reliable soil OC data at the beginning of these experiments in 1978 is not available. Consequently we modeled the carbon dynamics from the time the land was cleared from forest (1900 for Bhairahawa and Parwaninpur, and 1950 for Tarahara) to the beginning of the experiments. We used the regression for the maximum soil OC value obtained from our forest site survey (Figure 2) to determine the initial starting point for each site. Land use, crop yield and crop harvest index history in the region were used to develop mean values for estimated root C inputs (Table 4). Root C input values were estimated as 25% of total above ground biomass C. Individual site climate data were used.

Table 4. Parameters used to derive root residue inputs prior to start of long-term fertility experiments

Time Period	Cropping System	Mean Yield (t/ha)	Harvest Index	Estimated Root C Input (t/ha)
1900-1960[1]	R	0.95	0.3	0.317
1960-1978	RW	R 1.95	0.35	0.557
		W 1.5	0.44	0.340

[1]1950-1960 at Tarahara

Modeling for the experimental period onwards to 2080 with the RothC model was based on mean crop data for the 25 year experimental period. However, with Century it was based on predicted yield trends to 2030.

RothC Results

For this model we estimated that the inert SOM pool was 75% of the minimum value calculated for rice-wheat systems from the regression equation established for data from our survey of rice-wheat sites (Figure 2). The model provide a fairly good fit to the single data points for the Bhairahawa and Parwanipur experiments but overestimated soil OC content at Tarahara, especially for the FYM treatment (Figure 4). Derived values for the maximum and minimum soil OC values observed for rice-wheat farms (Figure 2) are shown to provide a perspective. The rice-wheat minimum value was being approached at Bhairahawa and Parwanipur. None of the

NPK treatments approached the rice-wheat maximum value, suggesting that the latter is associated with sites that have received FYM.

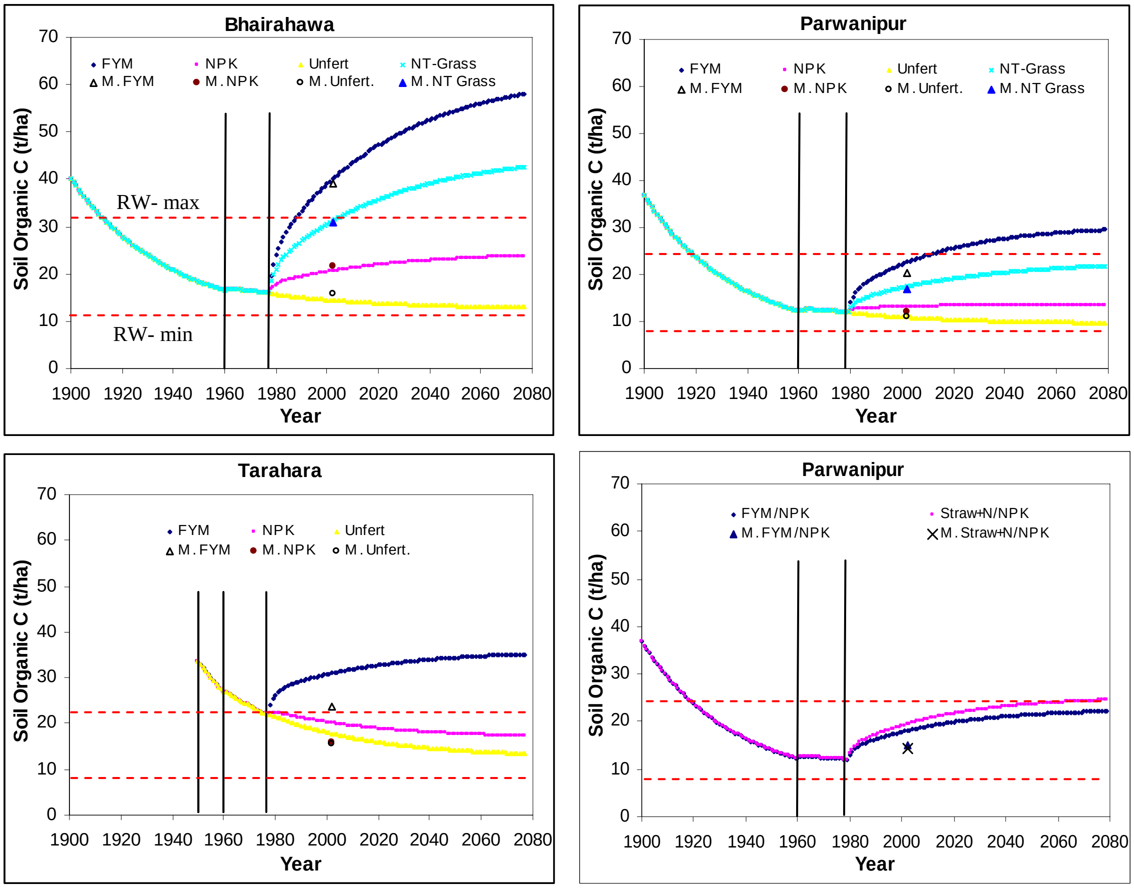

Figure 4. RothC modeled soil C dynamics for long-term soil fertility experiments

The grassland data point was fitted by finding the appropriate residue input value rather than being empirically derived; the residue input values were 5 and 2.5 t C/ha, respectively for Bhairahawa and Parwanipur. These values seem unreasonably large and we conclude that rate constants in RothC will likely need to be modified by a tillage factor.

Century Results

We have only use Century to model the results at Bhairahawa. For this site, the model predicted the soil C content for the NPK treatment, but underestimated soil C content for the FYM and unfertilized treatments and for the grassland (Figure 5).

Century differs from RothC in that it predicts C inputs from a crop growth model, whereas RothC requires that all C inputs are specified. The crop growth model is unnecessary for most agricultural situations because root inputs of C vary little with crop yield and residue inputs from plant tops are generally known. So far, we have not been able to get Century to accurately predict crop yields in the Bhairahawa long-term experiment (Figure 6 as example). This may be because the factors causing the observed yield decline with time are not captured by the crop growth model.

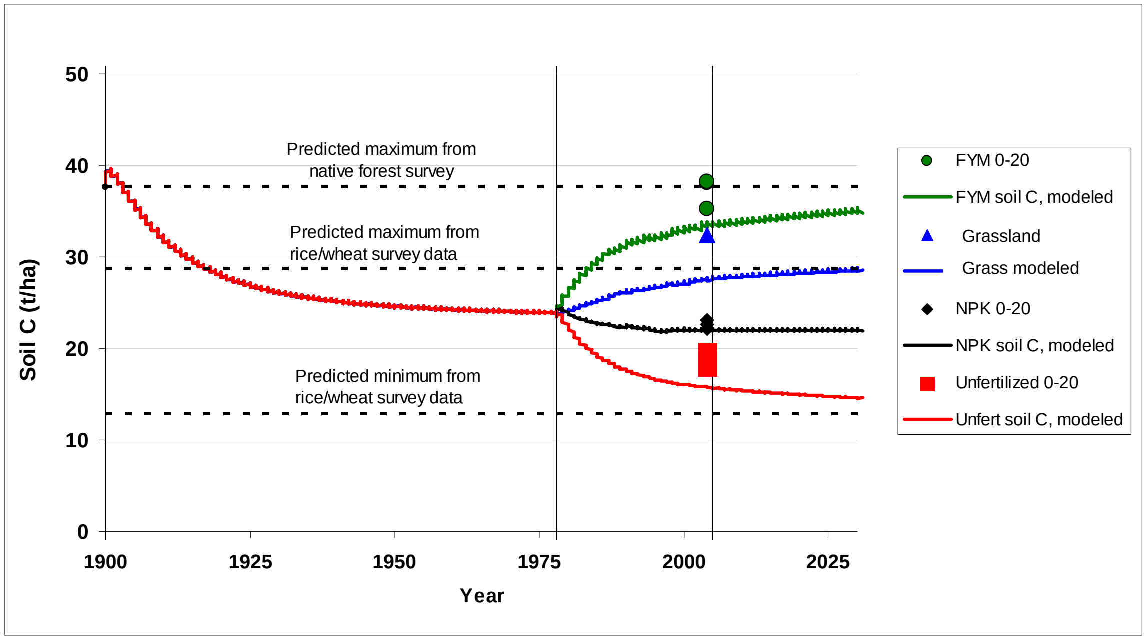

Figure 5. Century modeled soil C dynamics for Bhairahawa long-term soil fertility experiment

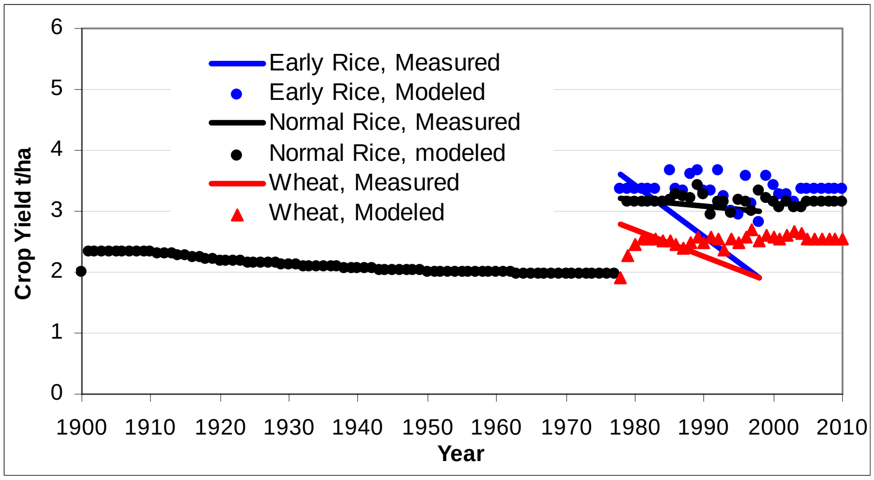

Figure 6. Crop yield for NPK treatment at Bhairahawa long-term fertility experiment: Century modeled yield is shown as symbols, measured yield is shown as solid lines, which are linear regressions of measured yield data

Modeling Issues

- An important aspect of the models for our purposes is their ability to accurately predict the future. Currently, Century and RothC predict very different scenarios for the future of the

Bhairahawa experiment. Reasons for this are being investigated. The RothC model predicts that C stocks will change a lot over the next 75 years, especially for the FYM treatment and the grassland. This pattern seems unreasonable for this environment. In contrast, Century suggests that soil C stocks will essentially reach equilibrium values within 50 years of the start of the experiment, which seems more plausible.

- RothC does not seem to be limited by a lack of rate constant adjustment for anaerobic conditions but may well need a tillage parameter.
- Neither of the models has adjustments for soil bulk density, so the data points shown in the RothC model (Figure 4) are adjusted to a constant soil mass based on the NPK treatment.

III. Financial Statement

Provided Separately

IV. Statistical Summary

IVa. Participating and Collaborating Scientists and Institutions/Organizations

South Asia

Country	Name	Discipline	Institution
Bangladesh	Bodruzzaman, M.	Soil Chemistry	BARI
	Hossain, M.I.	Agronomy	BARI
	Paul, Dr. D.N.S.	Statistics/GIS	BRRI
	Talukder, A.M.H.S.	Agronomy	BARI
India	Gupta, Dr. R.K.	Soil Science, Facilitator Rice-Wheat Consortium	RWC-CIMMYT
Nepal	Basnet, Dr. K	Agronomy	IAAS
	Dahal, K	Agronomy	IAAS
	Giri, G.S.	Agronomy	NARC
	Justice, S.	Anthropology & Engineering	ITDG
	Maskey, Dr. (Mrs.) S.M.	Crops Director	NARC
	Rai, S.	Soil Science/GIS	NARC
	Sah, Dr. S.C.	Soil Science	IAAS
	Sah, G.	Agric. Engineering	NARC
	Scherchand, Dr. K.	Environmental Science	NARC
	Shrestha, Dr. S.M.	Plant Pathology	IAAS
	Tripathi, J.	Agronomy	NARC
	Tuladhar, Dr. (Mrs.) J.	Soil Science	NARC

Cornell University

Name	Department/Discipline	Institution
Adhikari, C.	Agronomy	NARC/Cornell Nepal Country Coordinator
Duxbury, Dr. J.	Crop & Soil Science	Cornell Univ.

Name	Department/Discipline	Institution
De Gloria, Dr. S.	Crop & Soil Science	Cornell Univ.
Hobbs, Dr. P.	Agronomy	Cornell Univ.
Lauren, Dr. J.	Crop & Soil Science	Cornell Univ.
Woodbury, Dr. P.	GIS & Carbon Modeling	Cornell Univ.

Other Developed Country and CGIAR Institutions

Name	Discipline	Institution
Easter, Dr. M.	CENTURY Carbon Modeling	Nat. Res. Ecol. Lab Colorado State Univ.
Gaunt, Dr. J.	Soil Chemistry/Organic Matter	GY Associates
Meisner, Dr. C.	Agronomy	IFDC & Cornell Univ.
Sayre, Dr. K.	Agronomy	CIMMYT-Mexico
Williams, Dr. S.	CENTURY Carbon Modeling	Nat. Res. Ecol. Lab Colorado State Univ.

IVb. Publications, Reports and Presentations

<u>Presentations</u>

Gami, S.K., J.M. Duxbury, and J.G. Lauren. 2006. Influence of soil texture and management practices on soil organic carbon stocks in Nepal. 18th World Congress of Soil Science. 9-15 July 2006. Philadelphia, PA.

Hossain, M.I., C.A. Meisner, M.A. Sufian, J.M. Duxbury, J.G. Lauren, M.M. Rahman. 2005. p. 888-889. Use of nutrients on raised beds for increasing rice production in rice-wheat cropping systems. *In* C.J. Li et al. (ed.) Plant nutrition for food security, human health & environmental protection. Proc. 15th Int. Plant Nutrition Colloquium. 14-19 September 2005. Beijing, China. Tsinghua Univ. Press. Beijing, China.

<u>Thesis/Dissertations</u>

Adhikari, J.B. 2006. Effect of different combinations of mulching materials on weed growth and rice yield using the leaf color chart for nitrogen management. Tribhuvan University – Institute of Agriculture and Animal Science. Rampur, Nepal. 101 pp.

Aryal, M. 2006. Effect of tillage and mulching on the soil micro-flora and the incidence and intensity of rice and wheat diseases. M.Sc. Thesis. Tribhuvan University – Institute of Agriculture and Animal Science. Rampur, Nepal. 101 pp.

Ghimire, R. 2006. Soil organic carbon sequestration by tillage, nitrogen & mulch management in a rice-wheat cropping system of the Chitwan Valley, Nepal. M.Sc. Thesis. Tribhuvan University – Institute of Agriculture and Animal Science. Rampur, Nepal. 122 pp.

Nepal, A. 2006. Effect of different combinations of mulching materials on nitrogen, phosphorus and potash uptake by rice plants. M.Sc. Thesis. Tribhuvan University – Institute of Agriculture and Animal Science. Rampur, Nepal. 157 pp.

IVc. Training

Non-Academic Training

None

Academic Training

Name	Home Country	Gender	Major	Degree	Grad. Date	Major Advisor
Cornell University						
Sanjay Gami	Nepal	male	Soil Science	PhD	2006	Prof. J. Duxbury
Tribhuvan University-Institute of Animal and Agricultural Science						
Arati Nepal	Nepal	female	Soil Science	MSc[1]	2006	Dr. S.C. Sah
Mahendra Aryal	Nepal	male	Plant Pathology	MSc[1]	2006	Dr. S.M. Shrestha
Rajendra Gautam	Nepal	male	Soil Science	MSc	2007	Dr. S.C. Sah
Deepak Sapkota	Nepal	male	Agronomy	MSc.	2007	K.R. Dahal
Puspa Poudel	Nepal	male	Agronomy	MSc.	2007	Dr. K. Basnet
Shyam Kandel	Nepal	male	Plant Pathology	MSc.	2007	Dr. S.M. Shrestha
Nabin Dangel	Nepal	male	Plant Pathology	MSc.	2007	D. Sharma

IVd. Acronyms

BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice research Institute
CIMMYT	International Maize and Wheat Improvement Center
GIS	Geographic Information Systems
IAAS	Institute for Agriculture and Animal Science (Rampur, Nepal)
IDTG	Intermediate Technology Development Group
LOI	Loss on ignition method of carbon analysis
NARC	Nepal Agricultural Research Council
OC	Organic carbon
RWC	Rice Wheat Consortium
SM-CRSP	Soil Management Collaborative Research Support Program
SOC	Soil organic carbon
TOC	Total organic carbon
WB	Walkely Black method carbon analysis