Annual Report

July 1, 2003 - June 30, 2004

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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II. Executive Summary

Activities in this year focused on:

1. Development of soil organic carbon-texture relationships for cultivated and native soils;
2. Determination of soil organic carbon stocks in a number of our tillage and residue management experiments in Nepal;
3. Initiation of two experiments on soil carbon and crop residue dynamics using ^{13}C tracer techniques; and
4. A preliminary assessment of the maximum potential for C sequestration in soils of Rupandehi district, Nepal.

Highlights were:

- Soil organic carbon measurement issues are slowly being resolved. A simple method for removal of carbonate has been successfully used to improve combustion data and the Mebius modification to the Walkely-Black method appears to improve wet digestion analyses. However, difficulties in reliably measuring soil organic carbon remain.

- Data from more than 250 surface soil samples from rice-wheat areas in Bangladesh and Nepal was used to establish a mean and a minimum soil organic carbon content as a function of soil texture (silt + clay).

- Published relationships between soil organic carbon and texture for native tropical soils predicted higher levels of carbon than relationships we found for soils from Chitwan National Park in Nepal and from the Brazilian Cerrados.

- Tillage and residue management practices significantly altered soil carbon stocks in 2 of 3 experiments analyzed. One experiment showed an annual increase of 0.375 tC/ha over a 7 year period when puddling of soil for rice was stopped. Another experiment showed that carbon retention from a mixture of wheat and rice straw additions was 10 % over a 7 year period with an annual gain of 0.21 tC/ha.

- Two experiments with ^{13}C tracers were initiated. One investigates the relative importance of root and top inputs to soil organic carbon content under conventional tillage and zero tillage. The other will determine the relative decomposition rates of wheat and rice straws for use in modeling C accumulation rates from straw additions.

- Two farmer groups in Nepal were provided zero till drills to determine how they would respond to the technology. One group did not like the drill but a second group was more positive and will continue to use it for a range of crops.

- A preliminary assessment of the maximum potential carbon sequestration in soils of Rupandehi district, Nepal gave values ranging from 1.7 to 6.5 x 10^6 tC for the 115,000ha, depending on the soil C-texture relationship used for native soils. This estimate is likely to be considerably reduced as the analysis is refined.

I. Introduction

Our overall approach to carbon sequestration in soils in based on the following hypotheses or tenets, which are summarized in Figure 1:

- Soil aggregation, which varies with soil texture, is the primary variable controlling soil organic carbon (SOC) levels in tropical soils.
- Soil texture is a good surrogate for total aggregation of soils only in the absence of tillage.
- Tillage causes loss of soil organic matter through destruction of macro-aggregates and microbial mineralization of the "physically protected" soil organic matter pool.
- Micro-aggregates and their associated SOC are stable to tillage, and this "passive or chemically protected" SOC pool represents the minimum level of SOC.

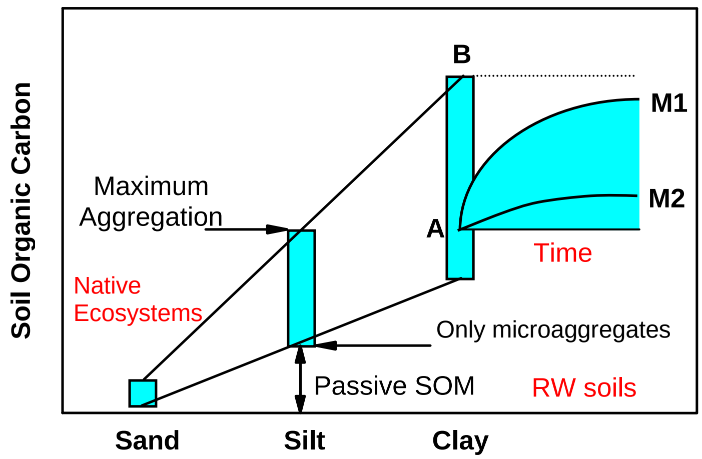


Figure 1. Conceptual model for soil organic carbon

Undisturbed, native forest or grassland soils, where macro-aggregation is at a maximum, define the upper limit for SOC. In contrast, SOC in rice-wheat soils of South Asia should be close to the lower limit because puddling of soil for rice has destroyed macro-aggregates, leaving only SOC associated with the passive pool in micro-aggregates. The difference between these two limits is physically protected SOC, controlled by tillage. Unfortunately, ***the rotation of flooded (paddy) rice with wheat or any other upland crop leads to the most carbon degraded surface soils in the world*** because of the intense physical destruction of aggregates followed by aerobic conditions that enhance biological decomposition processes.

Soil in a farmer field may be anywhere between the upper and lower lines depicted in figure 1; for example it may be a clay soil with the SOC content at point A. By reducing tillage, SOC levels will increase over some time frame to a new equilibrium level, which, for various reasons, will most likely be less than the maximum or saturation carbon content of a soil shown by point B and the upper dashed line. Both the rate of increase in SOC and the new equilibrium SOC level will depend on the particular reduced tillage practice; for example practice M1 gives a different pattern of SOC accumulation and a higher equilibrium level than regime M2. The highest SOC level will, of course, be associated with no tillage.

II. Objectives

The specific objectives of our project are to:

1. Develop practical methods to measure gains and losses of soil organic C over time in spatially variable soils.
2. Apply methods to assess the potential for carbon sequestration for selected sites in South Asia.

III. Accomplishments

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

(i) Development of Soil C-Texture/Mineralogy Relationships

C measurement issues: In our 2002-03 report we discussed problems with carbon measurement by combustion in soils that contained carbonates; and lack of agreement between combustion and Walkely-Black (WB) methods for measuring SOC. A set of 90 surface soil (0-15 cm) samples collected from farms in Rupandehi district that had previously been analyzed for SOC by the WB procedure were analyzed by combustion, with and without treatment to remove carbonates. Because of the presence of carbonates total soil carbon was consistently higher than total SOC (figure 2, left panel). After removing carbonates, SOC by combustion and WB methods compared reasonably well ($r^2 = 0.78$) and the regression was close to the 1:1 line (figure 2, right panel). Outliers represented 5% of the samples, which is probably adequate for C trading purposes.

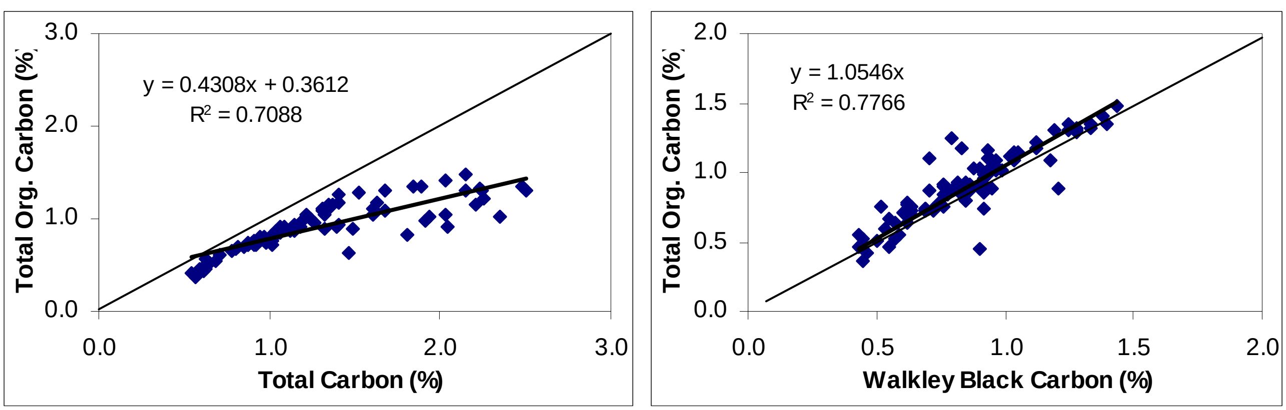


Figure 2. Effect of carbonate removal on C determination by dry combustion (left) and relationship between dry combustion and Walkely-Black measurements of SOC (right)

A second set of 105 samples collected from our tillage and crop establishment experiment were analyzed by combustion at Cornell (carbonate removed) and by the soils laboratory at NARC, Khumaltar. NARC used the Mebius modification to the WB procedure and the results were in good agreement ($r^2 = 0.89$) (figure 3). Despite longer processing time, the Mebius modification of WB appears to be a better analytical method than the standard WB method.

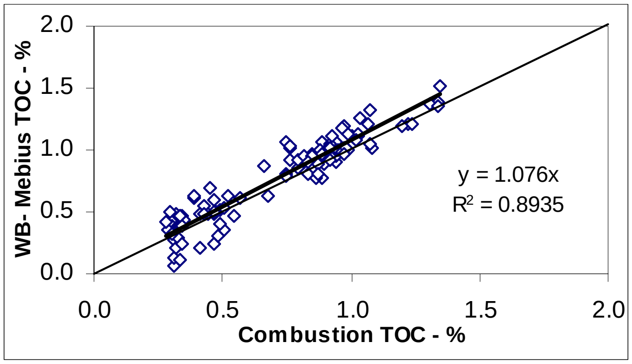


Figure 3. Comparison of SOC measured by modified Walkely-Black (Mebius) at NARC, Nepal and by combustion at Cornell U

The reasons for pursuing these analytical issues are:

1. Laboratories in developing countries need to demonstrate the capacity to measure SOC with precision and accuracy if they are to contribute to potential C trading opportunities, and

2. NARC has a data set of SOC and soil texture for almost 400 samples collected on a1 km^2 grid from Rupandehi district. We wish to use this data set to assess C sequestration potential and to study errors in assessment at different scales. We are not yet confident in the SOC values, which has limited our ability to undertake these activities (see section III, Objective 2).

Soil carbon-texture relationships: Rice-wheat surface soils (0-15 or 0-20 cm) from Bangladesh and Nepal increase in soil organic carbon (OC) as their silt + clay fraction increases (figure 4, left panel). The variability in the SOC/texture relationship is quite high – a range of ~ 1% OC (or about 20 tC/ha) for silt + clay contents greater than 50%. This variability may reflect differences in manure use, years under cultivation, tillage, sampling depth or length of time that soils are flooded. The lower line indicates the minimum level of carbon that can be found in these soils and this has an intercept of zero.

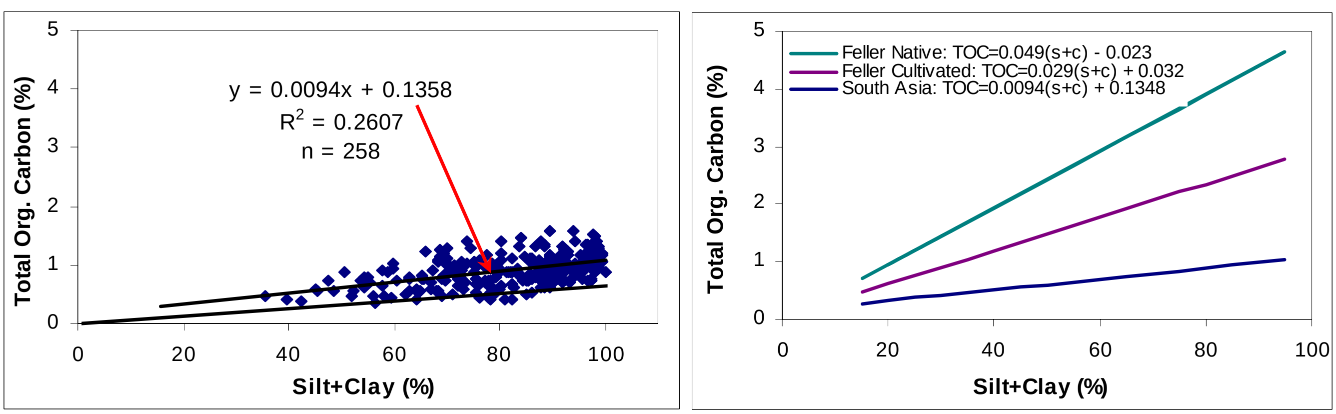


Figure 4. Relationships between SOC and texture for rice-wheat soils (left) and for native and cultivated soils from the tropics as determined by Feller and Beare (right)

Feller and Beare (Geoderma 79:69-116, 1997) have constructed relationships between SOC and soil silt + clay content for native (uncultivated) and cultivated upland soils collected from semi-arid to humid tropics. The Feller and Beare (F&B) regression lines are compared with our S.

Asia data for rice-wheat soils in figure 4 (right panel). The F&B regression for cultivated soils is considerably higher that that for soils from the rice-wheat system. One explanation for this difference is that it represents the effect of puddling of soils on losses of SOC. Our data for soils under native vegetation (0-15 or 0-20 cm) from Royal Chitwan National Park, Nepal and from across the Brazilian Cerrado show much lower SOC levels that those reported by F&B (figure 5). These differences are hard to explain as F&B did not find substantial effects of precipitation or mineralogy on SOC, except for allophanic soils that are not a factor in any of these data sets. We

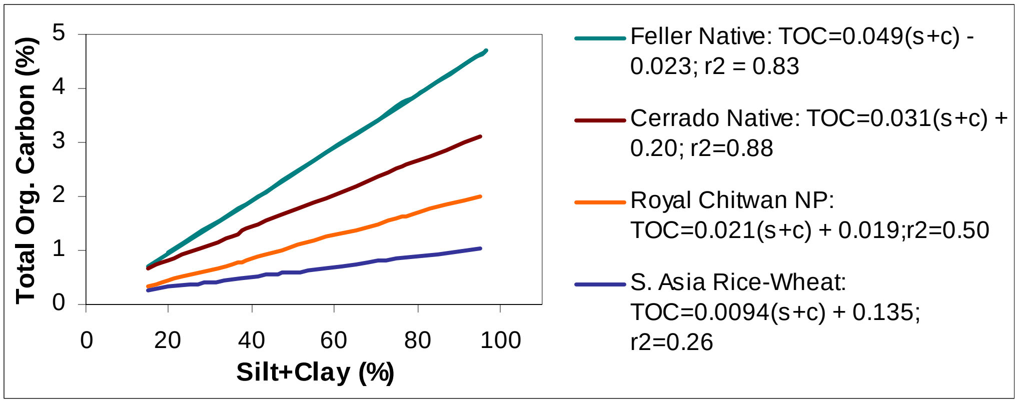


Figure 5. Relationships between SOC and soil texture for tropical soils under native vegetation

used a cut-off of 50 µm for the silt fraction, whereas F&B used 20 µm, which could make our SOC values lower by comparison. It is clear that we need additional data to define the SOC-texture relationship for uncultivated soils in S. Asia with confidence. An additional 36 samples of uncultivated soils have been collected from across the eastern terai region of Nepal and are currently being analyzed. Sites for further collections have been identified in Bangladesh.

It should be emphasized that all of the SOC-texture relationships show very low intercepts, indicating that significant amounts of OC will not accumulate in soils in these environments without the protective effects of interactions with mineral surfaces (as provided by silt/clay) and the formation of aggregates.

(ii) <u>Characterization of Organic C Gains from Sequestration Practices</u>

Carbon stocks were measured after rice 2003 in rice-wheat tillage and residue management experiments established in Nepal during phase I of the CRSP, together with a zero tillage experiment established at the beginning of phase II. A summary of these experiments is given in table 1.

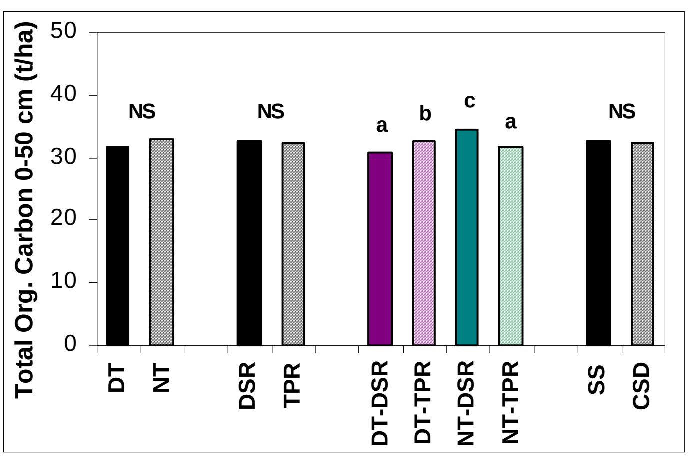
Analysis is complete for the first three of these experiments. In addition a long-term rice-wheat experiment at Parwanipur has been sampled and similar experiments at Bhairahawa and Pantnagar (India) will be sampled after rice 2004.

Table 1. Summary of tillage and crop residue experiments in Nepal

Experiment	Location	Treatments	Reps	Age (yr)
Tillage & Crop Establishment	Bhairahawa,	Deep tillage and normal tillage; Direct seeded and transplanted rice; Chinese seed drill and surface seeded wheat	3	7
Crop Residue Management	Bhairahawa,	No fert., no residue control; residue incorporated; residue as mulch; residue incorporated + added N	4	7
Mulch in Rice	Rampur	Mulch and no mulch on rice only	4	4
No-till Surface Seeding	Rampur	Initially mulch and no mulch surface seeded (ZT) Conventional tillage comparison added 2 yr ago	4	5
No-till Surface Seeding	Baireni	Surface seeding (ZT) and conventional tillage; Mulch and no mulch	4	2

All experiments were sampled by hand to a soil depth of 40 or 50 cm, using a 2.15 cm diameter tube auger with a quick release tip. At least 5 cores were collected in sections from each plot and composited by selected depth increments for bulk density and C determination. Care was taken to sample at soil moisture conditions where compaction did not occur or was minimal.

Tillage and Crop Establishment Expt., Bhairahawa: Carbon stocks to a depth of 50cm were between 30.9 and 34.4 t/ha. Overall, no significant differences in C stocks were found as a function of tillage or crop establishment methods (figure 6), however interactions between tillage and crop establishment for rice were signifcant. The deep tillage treatment involves annual sub-soiling to a depth of 50cm before rice followed by tillage of the surface soil (NT). The direct seeded (DSR) and transplanted (TPR) establishment methods for rice have the same surface soil tillage but soil is also puddled for TPR. Consequently differences between DSR and TPR represent the effect of puddling.



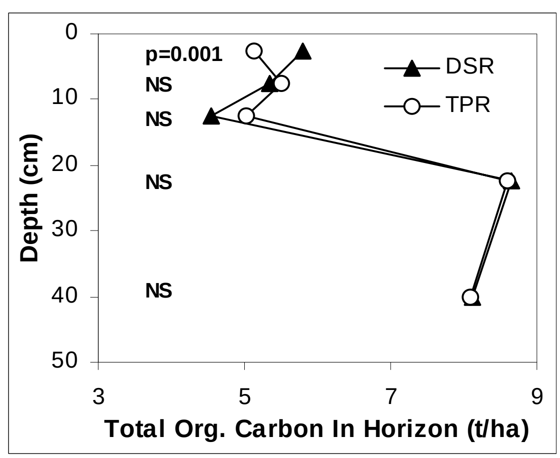
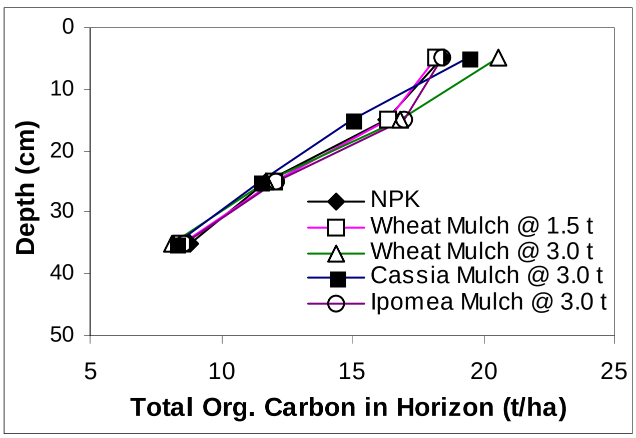


Figure 6. Soil organic carbon stocks after 7 years of a tillage and crop establishment experiment at NARC, Bhairahawa, Nepal

We expected to see higher carbon stocks in the DSR compared to the TPR treatments, because of the effects of puddling on aggregation/ SOC losses. Soil in the normal tillage-DSR treatment had a significantly higher carbon stock than all other tillage x crop establishment treatments. However, the C stock for the DT-DSR treatment was significantly lower than the DT-TPR treatment. These opposing effects of tillage and crop establishment were unexpected and may be due to mixing of soil at the interface between the plow layer and the sub-soil with deep tillage. The sampling protocol should be revised to reflect this situation. If only normal tillage data is used (on the basis that deep tillage is not practiced in the region) then DSR led to an increase in soil C of 2.625 t/ha compared to TPR. Therefore, without puddling of soil, the annual increase in soil C was 0.375 t/ha, which can also be applied to soils of similar texture. This value is higher than that (0.34 tC/ha) found for the global average for the switch from conventional tillage to no-tillage (West and Marland. Agric., Ecosyst. and Environ. 91:217-232, 2002).

Mulch in Rice Expt., Rampur: Carbon stocks ranged between 55 and 57 t/ha (figure 7) but no significant treatment effects were found. While wheat mulch at 3 t/ha/year appeared to increase carbon stocks relative to the other treatments, the result was not significant.



Treatment	Total C t/ha
No Mulch	
NPK	55.27
Mulch + NPK	
Wheat 1.5 t/ha	55.06
Wheat 3.0 t/ha	57.29
Cassia 3.0 t/ha	54.33
Ipomea 3.0 t/ha	56.16

Figure 7. Soil organic carbon stocks after 4 years of various mulch materials added to rice at IAAS, Rampur, Nepal

Crop Residue Management Expt., Bhairahawa: Carbon stocks to a depth of 40 cm were between 26.9 and 28.8 t/ha (figure 8 and table to right). Fertilizer input without residue had no effect on the soil carbon stock, indicating that the increased productivity of rice and wheat (average of 5.1 versus 3.4 t/ha for rice and 3.0 versus 1.2 t/ha for wheat for fertilized and control treatments, respectively) did not impact soil C contents. On average, soil C stock was increased by 1.48 t/ha where residues were added. The total amount of residues added over the 7 years of the experiment was 29.5 t/ha or (14.75 tC/ha). Thus C retention was 10% of that added or 0.21 tC/ha/yr. Carbon retention % will, of course, decline as SOC moves toward a new equilibrium level.

Treatment	Total C t/ha
No Residue	
Control	26.92
NPK	27.06
Mean	26.99
Residue + NPK	
Incorp.	28.63
Incorp.+ N	28.76
Mulch	28.03
Mean	28.47
ΔC Res.-No Res.	**1.48**

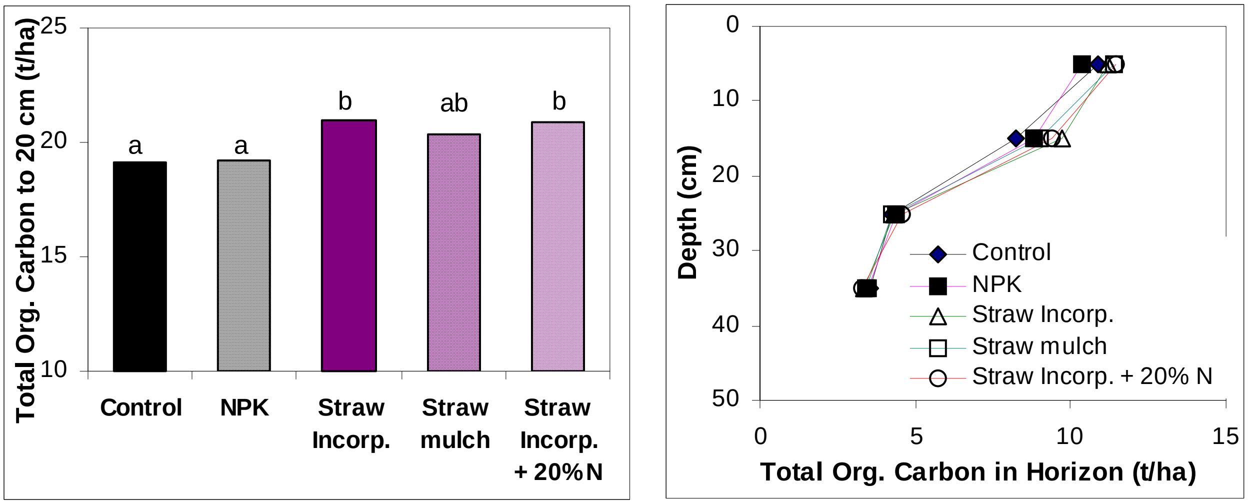


Figure 8. Soil organic carbon stocks after 7 years of a residue management experiment at NARC, Bhairahawa, Nepal

In all of these experiments there was no detectable change in SOC contents below a depth of 20 cm, indicating that sampling to a depth of 30 cm is adequate for assessment of changes in SOC stocks. While accuracy in determination of SOC is required, errors in bulk density measurements are, in our opinion, more of a constraint to assessment of SOC stocks. It would be desirable to collect individual complete cores of soil to the selected depth without compaction. This can be achieved with 5cm diameter cores using hydraulically driven coring machines; however these are not usually available in developing countries. With this approach the whole soil column of interest is collected and differences in mass between cores can be measured and carbon stock adjusted to a fixed soil weight. Hand sampling methods and corers require extreme care, and exactly the right soil moisture condition in finer textured soils, to measure the small differences in SOC stocks that are found in short-term experiments.

Effects of Tillage and Crop Residue Inputs on SOC Dynamics using ^{13}C Labelled Materials

Two experiments with ^{13}C labeled materials were initiated during the 2003 wheat season. These experiments will provide data for use in modeling carbon dynamics. The first experiment is a study of the dynamics of root and top carbon decomposition patterns in soil (and relative contributions to soil organic C) using in-field ^{13}C pulse labeling of rice and wheat. This experiment was initiated at two sites that have tillage experiments and a triple crop rice-wheat-mungbean rotation. The tillage experiments are:

- a comparison of permanent beds (a minimum tillage practice) with conventional tillage on the flat at Ranighat, Nepal; ^{13}C treatments were imposed at the start of 5th year

- a comparison of no-tillage surface seeding with conventional tillage and crop establishment practice at Baireni, Nepal; ^{13}C treatments were imposed at start of 3rd year

Wheat and rice crops were/are being labeled with ^{13}C in separate microplots and decomposition patterns of tops and roots are studied separately. Sites, ^{13}C labelling and soil sampling are shown in Figure 9.

Figure 9. Overview of Ranighat and Baireni experimental sites (upper); temporary Saran chambers in place for ^{13}C labelling; (middle); and initial sampling of soil near microplots (lower left) and after wheat harvest (lower right)

Four pairs of microplots for study of plant top and root decomposition were established at each site for each crop. Roots remaining in ^{13}C labeled microplots form the root treatment, while tops from labeled plants are placed in an adjacent unlabeled microplot for the tops treatment. Pulse labeling was initiated at tillering and continued at irregular intervals (depending on plant growth) up to flowering. Soils were sampled in increments to 30 cm at the beginning of the experiment for determination of baseline ^{13}C levels; after wheat to establish ^{13}C levels following the labeling; and will continue after each rice and wheat crop for as long as the ^{13}C signatures can be detected. This research is part of the PhD program of Sanjay Gami from Nepal. Pictures of the ^{13}C pulse labelling method and soil sampling strategy are shown in figure 10.

The second ^{13}C experiment is within the crop residue management experiment at NARC, Bhairahawa (described in previous section and figure 10). The purpose is to determine decomposition rates for rice and wheat straws, from a one-time application, in order to model

Figure 10. Overview of the crop residue management experiment (upper panels)- scientists in the left panel are (l to r) J. Tripathi, C. Adhikari, G. Giri and Dr. A. Regmi. Lower panels show a mulch treatment plot with the microplots for ^{13}C labelled rice and wheat straw (left); collection of remaining mulch after wheat harvest (center); and separation of remaining mulch from soil (right)

SOC accumulation from residue returns to soil. From previous observations, rice straw decomposes more readily than wheat straw. Rice and wheat straw were added to separate 1 m^2 microplots at the rate of 4 t/ha at the beginning of the 2003 wheat crop. Straw was either incorporated into soil prior to planting of wheat or applied as a surface mulch to be incorporated prior to rice. The ^{13}C labelled straws were generated by Dr. Sherchand under double atmospheric CO_2 levels in chambers at NARC, Khumaltar (see 2002-03 report).

Soil was sampled in increments to 40 cm prior to initiation of the experiment and again after wheat harvest. Mulch remaining after wheat harvest was removed from each mulch treatment, separated from contaminating soil, dried and weighed. It was then returned to the microplots. Of the 400g of residue that was applied to each microplot an average of 180g remained for rice and 227g for wheat. Soil will again be sampled after rice and each subsequent crop for as long as the ^{13}C signature of the straw C can be detected.

(iii) Farmer Use of Zero-till drills

As a link between our technology adoption and soil carbon sequestration projects, we decided to loan no-till drills to two farmer groups to see how receptive they were to adoption of no-tillage. The groups were both in the Chitwan district of Nepal and neither had previous experience with a no-till drill. One drill was provided to a group at Baireni village, where soil texture is fairly heavy and the other to a group at Parvatipur village, where soil texture is lighter. Each group had a farmer with a 4-wheel tractor who did custom tillage work and who took responsibility for the drill (figure 11). The tractor owners were sent to a one-day training on use of the drill at

Figure 11. Lead farmer at Parvatipur, Nepal with zero till drill (left); excellent crop stand of wheat after zero tillage (right)

NARC-Bhairahawa research station. The group at Baireni did not like the drill and only 2 farmers used it to plant wheat. Five farmers planted no-till wheat at Parvartipur where the drill was received more positively. A brief survey of the farmers who used the drill showed that:

- the drill reduced land preparation costs and increased speed of irrigation (faster movement of water across the field)

- the drill was good for wheat but they were not sure about using it for other crops
- a major question was what to do with FYM, which they routinely use
- weeds and plant stand were a problem for some farmers – the drive wheel required a smoother soil surface
- two farmers planted mungbean with the drill (one had a very poor stand and used it for feed) and three indicated that they would use it for rice.

The average wheat yield with the drill was 2.93 t/ha compared to 2.75 t/ha for conventional practice. The Baireni group were more interested in vegetable production so we will provide them with training on seedbed solarization and loan the drill to another group.

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

Our general approach to this objective for a given farmer site is to couple information on soil texture and current SOC content with knowledge of how SOC changes with adoption of carbon sequestration practices within a broader geographic analyses using GIS. We believe that it is useful to characterize the maximum potential C sequestration as well as the achievable C sequestration with different C sequestration practices and adoption scenarios. We hypothesize that for a particular soil texture, the difference between SOC under native vegetation (uncultivated) and a current cultivated site represents the maximum potential for C sequestration.

We selected Rupandehi district in Nepal as a test site, because both point and categorized data are available for texture and carbon. We are still resolving analytical problems with the point carbon data, so at this point we do not have an accurate map of current SOC contents for Rupandehi district. Instead we used the point texture data from the district (figure 12, upper left) and the texture vs SOC regression for cultivated South Asia rice-wheat soils (see page 4) to generate SOC contents for cultivated soils in the district. Similarly, generalized texture data (based on survey and landform features, figure 12, lower left)) were used to generate cultivated SOC contents at a more generalized scale.

As discussed earlier, various equations for texture vs SOC for native (uncultivated) sites have been established. To assess the range in potential SOC sequestration predicted by these equations, we utilized the Feller, Cerrado and Royal Chitwan NP equations (see page 5) to determine maximum SOC levels with the point data set (Feller equation also with generalized texture data set). The difference between the various maximum values and the cultivated values represents the maximum potential for SOC sequestration. Figure 12 depicts the potentials based on the Feller equation from the point texture data (upper right panel) and the generalized texture data (lower right panel).

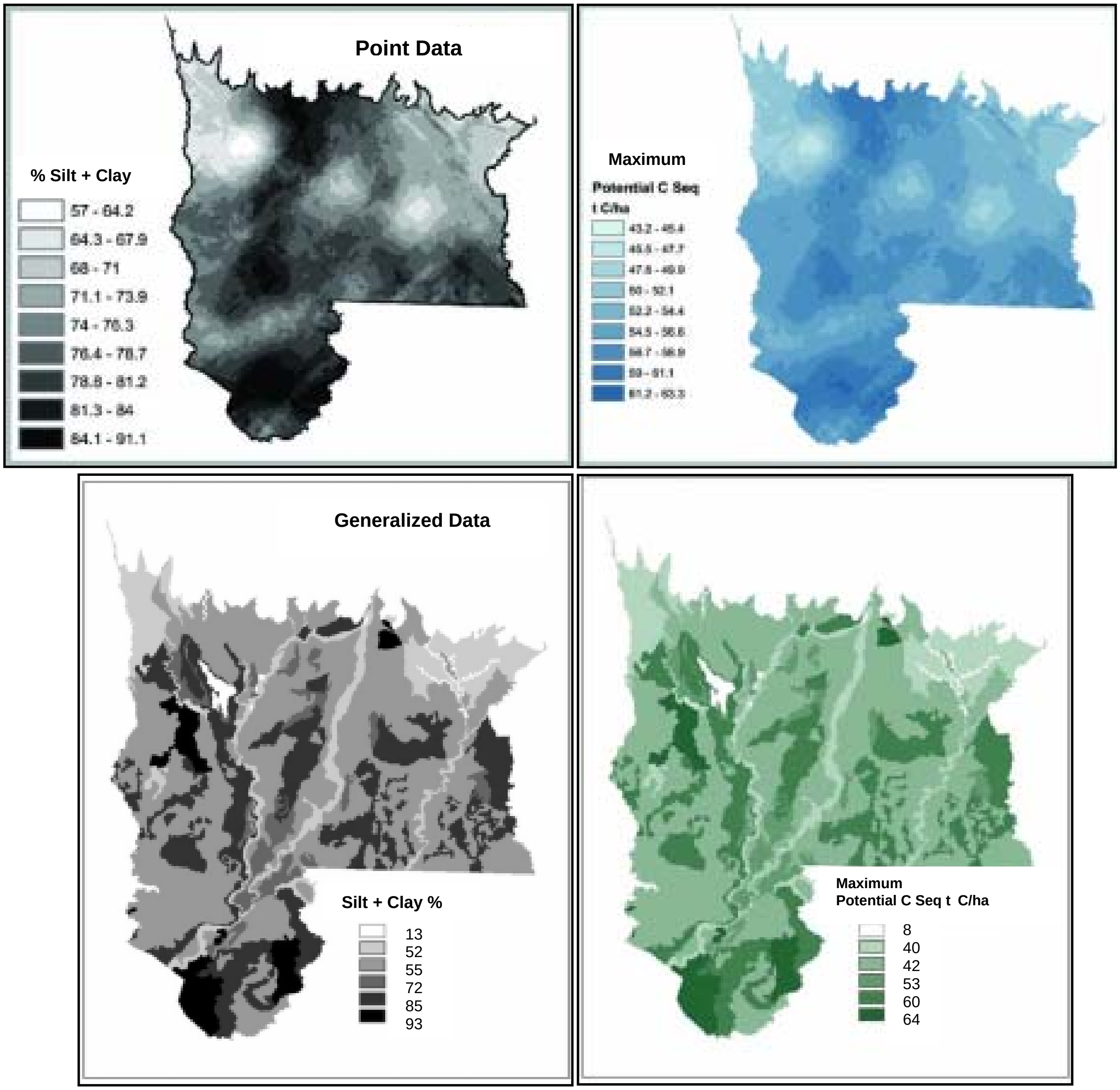


Figure 12. Maximum potential C sequestration maps of Rupandehi district, Nepal predicted from Feller's native equation and from point (top panel) and generalized texture data (bottom panel).

Summing the areas for each of these scenarios, we find total potential SOC sequestration for Rupandehi district (115,000 ha) varies between 1.7 x 10^6 tC to 6.4 x 10^6 tC (Table 2). Clearly the estimate with Feller's equation is elevated (approximately equal to 10% the C equivalent for annual greenhouse gas emissions for NY State or 1% of the global annual total). We expect this to drop considerably as our analysis is refined. The difference in potential SOC sequestration between the point texture data and the generalized texture data was only about 20%, suggesting that detailed texture data may not be necessary for this kind of analysis. This is pertinent since most texture data sets for developing countries are of the generalized type.

Table 2. Predicted maximum potential SOC sequestration for Rupandehi district with different texture data sets and native SOC equations

Texture Data	Native Equation	Cultivated Equation	Total Pot. SOC Seq. t Carbon
Point	Feller	South Asia	6.4×10^6
Generalized	Feller	South Asia	5.4×10^6
Point	Cerrado	South Asia	3.8×10^6
Generalized	--	--	--
Point	Royal Chitwan NP	South Asia	1.7×10^6
Generalized	--	--	--

V. Financial Statement

Provided Separately

VI. Statistical Summary

VIa. Participating Institutions and Scientists

(i) NARES

Country	Name	Discipline	Institution
Bangladesh	Baksh, M.E.	Agric. Economics	BARI
	Bhuiyan, Dr. N.I.	Soil Science-DG	BRRI
	Bodruzzaman, M.	Soil Chemistry	BARI
	Hossain, M.I.	Agronomy	BARI
Country	Name	Discipline	Institution
	Paul, Dr. D.N.S.	Statistics/GIS	BRRI
	Talukdhar, A.M.H.S.	Agronomy	BARI
India	Gupta, Dr. R.K.	Soil Science, Facilitator Rice-Wheat Consortium	RWC-CIMMYT
Nepal	Basnet, K	Agronomy	IAAS
	Dahal, K	Agronomy	IAAS
	Giri, G.S.	Agronomy	NARC
	Maskey, Dr. (Mrs.) S.M.	Head, Soil Science	NARC
	Munamkarmy, R.	Soil Science	NARC
	Pandey, S.P.	Soil Science/GIS/Admin.	NARC
	Rai, S	Soil Science/GIS	NARC
	Sah, G	Agronomy	NARC
	Sapkota, R.P.	Agronomy-Executive Director	NARC
	Scherchand, Dr. K	Environmental Science	NARC
	Shrestha, Dr. Sundar Man	Director Res., Plant Pathology	IAAS
	Tripathi, J.	Agronomy	NARC
	Tuladhar, Dr. (Mrs.) J.	Soil Science	NARC

(ii) Cornell University

Name	Department/Discipline	Institution
Adhikari, C.	Agronomy	NARC/Cornell Nepal Country Coordinator
Duxbury, Dr. J.	Crop & Soil Science	Cornell Univ.
DeGloria, Dr. S.	Crop & Soil Science	Cornell Univ.
Lauren, Dr. J.	Crop & Soil Science	Cornell Univ.
Lee, Dr. D.	Agric. Economics	Cornell Univ.
Riha, Dr. S.	Biophysical Modeling	Cornell Univ.

(iii) Other Developed Country and CGIAR Institutions

Name	Discipline	Institution
Hobbs, Dr. P.	Agronomy	CIMMYT-Nepal & Cornell Univ.
Justice, S.	Anthropology & Engineering	CIMMYT-Nepal
Meisner, Dr. C.	Agronomy	CIMMYT-Bangladesh & Cornell Univ.
Gaunt, Dr. J.	Soil Chemistry/Organic Matter	GY Associates

VIb. Publications, Reports and Presentations

<u>Peer Reviewed Publications</u>
Duxbury, J.M. **Add Title**
Climate Change, Carbon Dynamics and World Food Security Workshop at The Ohio State University. 10-11 June 2003; Columbus, OH (In press).

<u>Thesis/Dissertations</u>
Bhatta, Gopal Datt. 2003. Sustainability of productivity in rice-wheat system through nitrogen levels and mulching materials. M.Sc. Thesis. Tribhuvan University-Institute of Agriculture and Animal Science. Rampur, Nepal. 250 pp.

Gairhe, Janma Jaya. 2003. Soil productivity and fertility status in different regions of the Chitwan Valley. M.Sc. Thesis. Tribhuvan University-Institute of Agriculture and Animal Science. Rampur, Nepal. 100 pp.

McDonald, A.J. 2003. Optimizing agronomic practices for rice-wheat systems on valley terraces. Ph.D. Dissertation. Cornell Univ. Ithaca, NY. 193 pp.

VIc. Training

Name	Home Country	Gender	Major	Degree	Grad. Date[1]	Major Advisor
Cornell University						
Sanjay Gami	Nepal	M	Soil Science	Ph.D	2006	Prof. J. Duxbury
Andrew McDonald	US	M	Cro Physiology	Ph.D	2003	Prof. S. Riha
IAAS, Rampur						
Gopal Bhatta	Nepal	M	Agronomy	MS	2003	Dr. Basnet
Jagadish Kuinkel	Nepal	M	Soil Science	MS	2004	K. Dahal
Janma Gairhe	Nepal	M	Soil Science	MS	2003	L. Amgain

[1]See publication list for dissertation/ thesis titles

VId. Acronyms

BARI	Bangladesh Agricultural Research Institute
BRRI	Bangladesh Rice research Institute
CIMMYT	International Maize and Wheat Improvement Center
CRSP	Collaborative Research Support Program
CSD	Chinese seed drill
DSR	Direct seeded rice
DT	Deep tillage
GIS	Geographic Information Systems
IAAS	Institute for Agriculture and Animal Science (Rampur, Nepal)
NARC	Nepal Agricultural Research Council
NARES	National Agricultural and Extension Systems
NT	Normal Tillage
OC	Organic carbon
SOC	Soil organic carbon
SS	Surface Seeding
TPR	Transplanted rice
WB	Walkley-Black method for carbon determination
ZT	Zero tillage (surface seeding)