Interim Annual Report

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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. Introduction

The objectives of our project on soil carbon sequestration 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.

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.

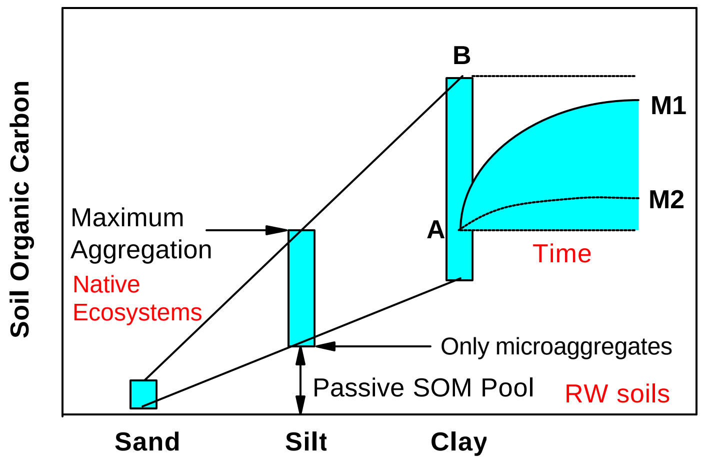

Figure 1. Conceptual model for soil organic carbon

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.

The conceptual model in figure 1 establishes the boundaries for SOC levels and provides the framework to assess soil carbon sequestration over time at the field scale. Characterization of SOC gains associated with reduced tillage will be done through a mixture of experimental measurement and modeling. Our general vision for quantitative estimation of SOC sequestration at landscape or larger scales is to use GIS spatial analysis with various data bases (soil texture, current SOC levels, impacts of reduced tillage practices on SOC dynamics as a function of texture) and scenarios. The probability of adoption of reduced tillage practices will also be considered in order to determine "achievable" C sequestration amounts.

II. SOC-Texture Relationships

The initial step in our project is to establish the upper and lower limits of the soil texture - SOC relationship for soils of the Indo-Gangetic plains (IGP). To determine the lower limit relationship, SOC and texture data were measured on archived soil samples collected during phase 1 of the SM-CRSP from rice-wheat sites in the following areas:

- Rupandehi district, Nepal – mid-Terai; 90 sites; 1991
- Birgunj district, Bangladesh – northwest Bangladesh; 50 sites; 2000
- Chuadanga district, Bangladesh – west central Bangladesh; 66 sites; 1999

Soil samples (107) obtained from a 1995 CLIMA-NARC legume survey across the Nepal Terai were also used, and we assume that these were from rice-legume rotations as rice is grown throughout the Terai in the monsoon season.

Figure 2 shows the relationship between soil silt + clay content and C for all of the soils, where soil C was determined by combustion with no acid pre-treatment. Measured C in these

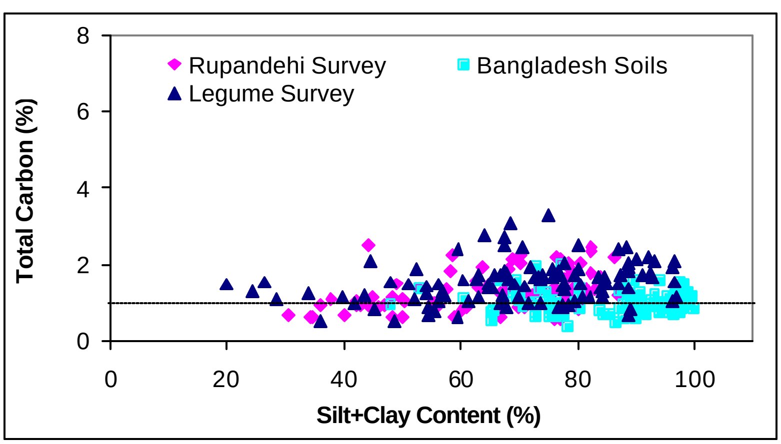

Figure 2. Relationship between soil C and texture for rice-wheat Soils

soils ranged from 0.4 to 3.3% and averaged 1.3%. The legume survey provided the widest range of soil textures, followed by the Rupandehi data. The Bangladesh soils tended to cluster around the finer textures. There was, however, no relationship between silt+clay content or clay content and soil C. Many of the soil C values were higher than expected (<0.5 to 1%), suggesting that carbonate could be present in these soils. Plots of soil C versus δ^{13}C confirmed that this was the case; the sites were all originally forested (C3 plants) and have been cropped to C3 plants, so should have a δ^{13}C signature between -26 and -28 ‰. Carbonate-C has a δ^{13}C of 0 ‰ (C4 crops have a δ^{13}C of -10 to -12‰).

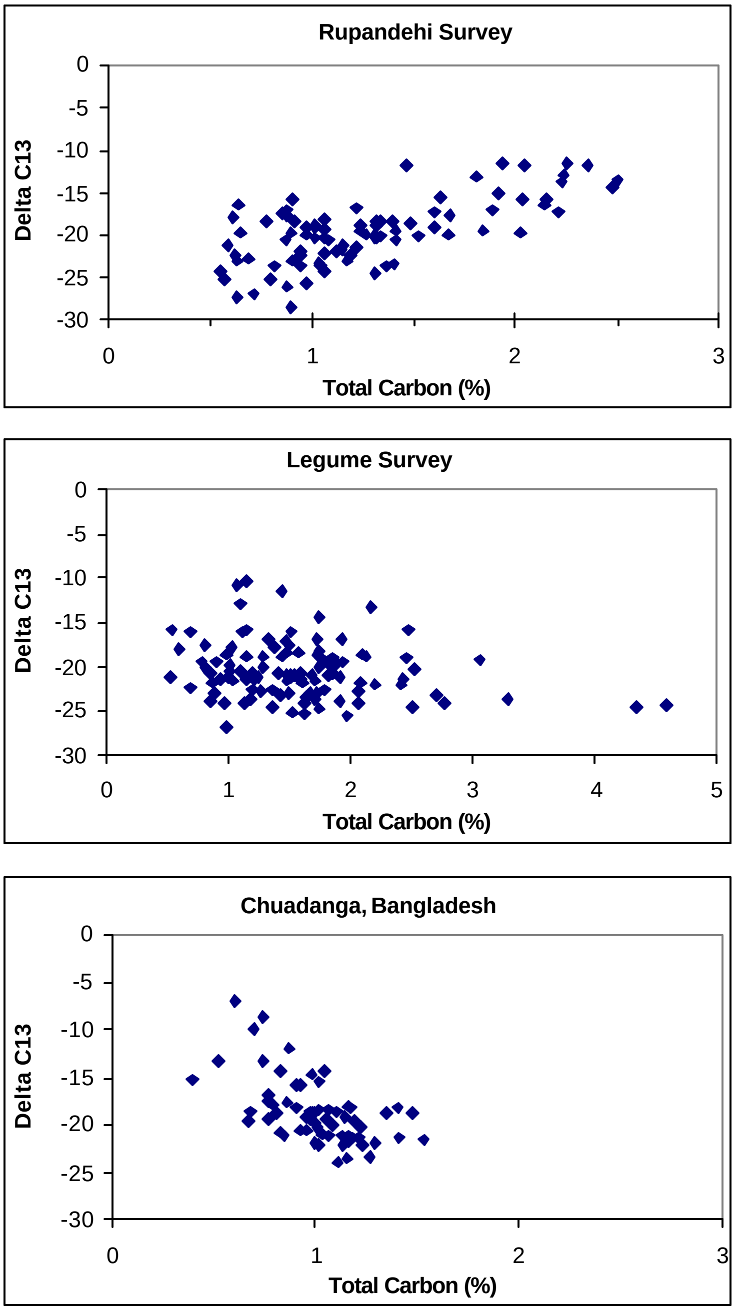

Figure 3. Relationship between δ^{13}C signature and soil C content for rice-wheat soils

Combustion soil C values were generally higher than SOC determined by the Walkley-Black method for both the Rupandehi and Bangladesh surveys (Figure 4), which is consistent with carbonate being present in the samples used for combustion. An excellent relationship (r^2 = 0.94) was found for combustion soil C data for the Rupandehi samples analyzed at Cornell and at IRRI, but values differed by 20%, suggesting a difference in calibration between the two laboratories (Figure 4).

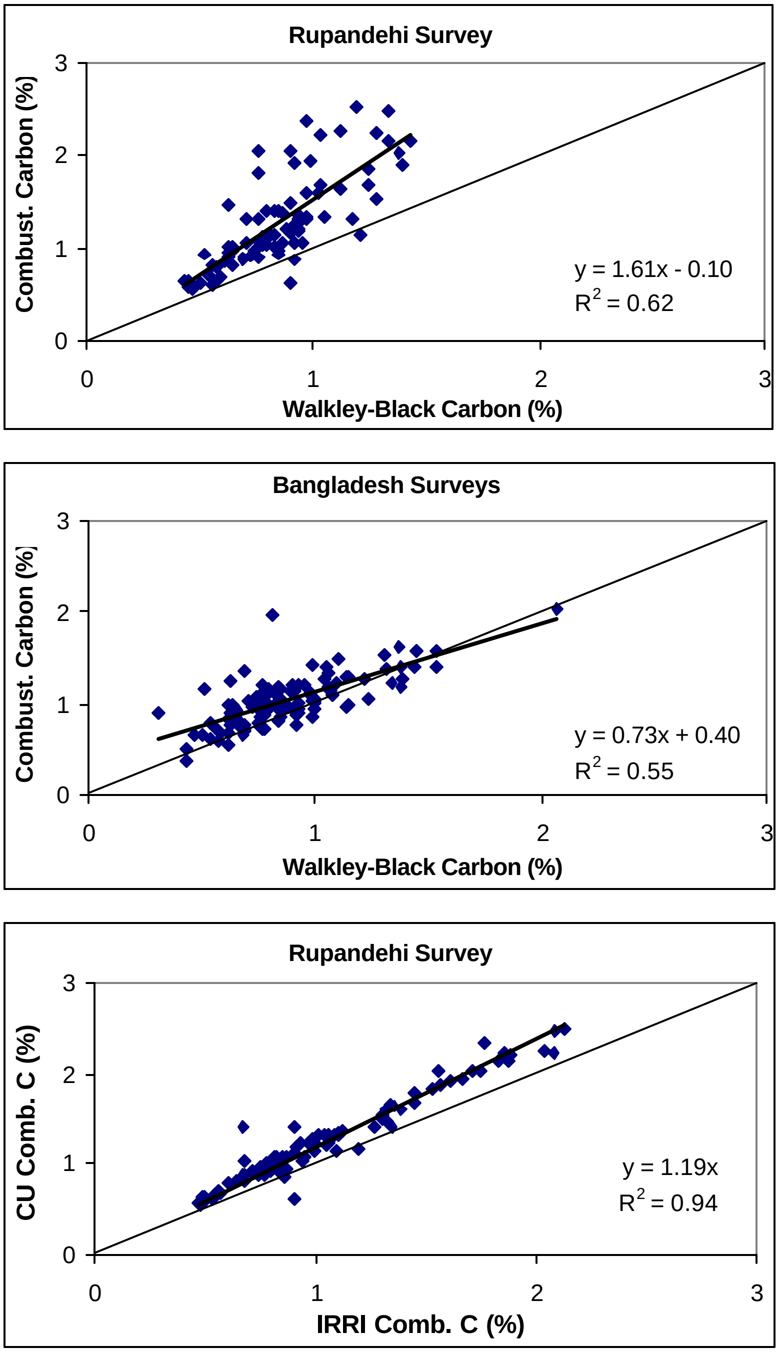

Figure 4. Comparison of combustion and Walkley-Black measurements of soil C and combustion measurements at Cornell and IRRI

Complete removal of carbonate from soils is often not achieved by simply adding acid to soils and the reasonable correlations between combustion and Walkley-Black C data for the Rupandehi ($r^2 = 0.62$) and Bangladesh ($r^2 = 0.55$) surveys also suggest incomplete removal of carbonate in the Walkley-Black procedure. Our experience is that soils must be ball-milled before acid treatment in order to get complete carbonate removal, especially from finer textured soils. This creates a problem for the combustion method where soils are weighed into small tin capsules that partially dissolve when acid is added. Treatment of samples with acid before weighing creates a complex procedure because of weight changes associated with acid treatment. A recently published procedure () using silver capsules and HCl vapor did not solve the problem for us. We have, however, developed a procedure using HCl treatment of samples contained in tin disks pressed into a bowl shape that is simple and reliable. Re-analysis of our samples is underway.

We have persisted with the combustion method because this is widely considered to be the "gold standard" (quote from G. McCarty) for C analysis. However, Walkley-Black is the standard method for SOC analysis in South Asia and most developing countries. A recent study reported by McCarty, Kimble, Reeves and Yost (2002 ASA) indicated that the Walkley-Black method under-estimates organic carbon at values less than 1%.

Despite the uncertainties in our SOC values, these are compared with data obtained from recent literature for natural ecosystems (tropical forests, savannas) (Figure 5). Significant

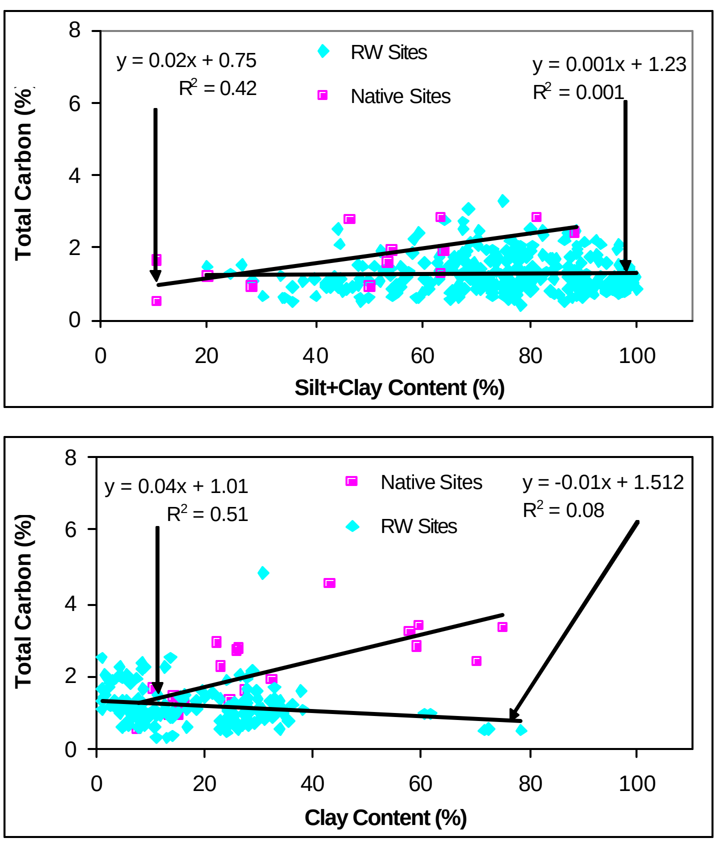

Figure 5. Relationship between soil C and texture for rice-wheat and native ecosystem sites

positive relationships obtained for the native ecosystem sites, with 42% and 51% of the variability in SOC accounted for by silt + clay and clay contents, respectively. The general pattern of soil C levels also shows the expected separation between native and cultivated sites.

Global soil carbon data were also utilized to investigate the soil texture-carbon relationship under native and agricultural land use practices outside the South Asian region. The WISE Global Soil Profile Database from the International Soil Reference and Information Center

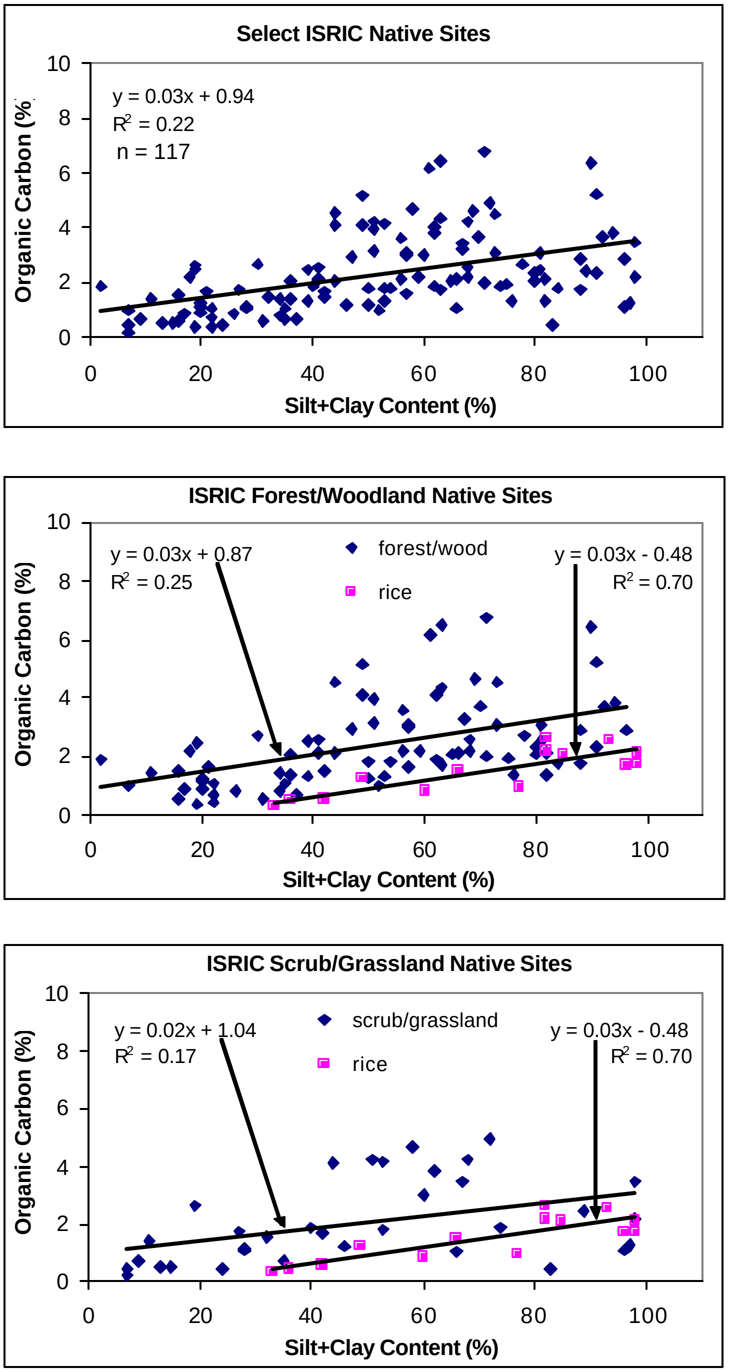

Figure 6. Relationships between soil C and texture for soils in the IRSIC database

(ISRIC) contains geo-referenced data from 4382 soil profiles worldwide including site descriptions, soil classification as well as soil chemical and soil physical parameters. Most of the SOC measurements were made using the Walkley Black method, with some by combustion. Data for soils in tropical latitudes were extracted from the MS Access database file (Batjes, N.H., 2002; http://www.isric.org) and sorted into agricultural (all crop agriculture; n = 142) and native (forests, woodlands, scrub and grasslands; n = 512) land use categories. Data for arid climates, obvious O-horizons and soils derived from volcanic ash were then excluded, leaving 101 and 117 samples for the agricultural and native and land use categories, respectively.

A significant positive relationship was found between silt + clay content and SOC (Figure 6 upper panel) for the wet, native ISRIC sites, but only 22% of the variation in SOC was described by the silt + clay content. Separating the forest and grassland land use categories changed the relationship only slightly (Figure 6, middle and lower panels). There was no relationship between soil texture and SOC for agricultural soils in general, but a significant positive relationship was obtained where rice was the crop (n = 13). For rice, 70% of the variation in SOC was explained by the silt + clay content (figure 6, middle panel). Since the rice data was from SE Asia, we are confident that they were for paddy rice, but may not be for rice in rotation with upland crops.

Problems in using the ISRIC database included variable sampling depth, uncertainties in interpretation of the native land use categorization, different analytical methodologies and uncertainty about pre-treatment of soils with acid.

Preliminary Conclusions

1. The data generated by us and taken from the ISRIC global soil database indicate that our conceptual model is generally correct. However, we have limited data from natural ecosystems and there is much variability in the data from rice-upland crop rotations. Next steps should include (i) collection of more extensive data for native ecosystem sites where SOC is judged to be at equilibrium, and (ii) assessment of the reasons for variability in the agricultural sites. Carbonate appears to be interfering with both combustion and Walkley-Black methods for determination of SOC.

2. Methodology issues that need to be addressed in determination of SOC for carbon sequestration purposes are:
   - use of procedures that assure carbonate removal from soils (or no interference)
   - comparisons of SOC stocks, rather than % C in surface soils; measurements should be made to a sufficient depth to capture differences in SOC content
   - the robustness of different methods of SOC determination amongst different laboratories should be assessed to determine if there is one method that can be recommended

3. Once methodolgy issues are resolved, reasons for remaining variability in the soil texture SOC relationships for IGP soils need to be considered. Possible remaining causes of variability are differences in soil mineralogy, climate, organic inputs (especially animal manure) and time since land clearing (applies to Terai regions of the IGP). Mineralogy and climate factors

relate to the accuracy of our conceptual model, manure use is a management factor and time since clearing affects whether SOC has reached the equilibrium value associated with the rice-upland crop rotation.

III. Reduced Tillage and Residue Management Experiments

Reduced tillage and residue management experiments are continuing from the first phase of our SM-CRSP project and one new one has been added. The goals for these experiments are to increase productivity and sustainability of the rice-wheat cropping system, in part through increasing SOC, and to increase economic returns to farmers. Meeting these goals will likely be critical to adoption of reduced tillage practices even with a carbon trading system. A listing of the various experiments is given in Table 1.

Table 1. Reduced tillage and/or residue management experiments

Description of Experiment[1]	Location[2]	Soil Texture	Estab'd
R-W-mungbean rotation; NT & CT; SS of R & W; ± straw mulch; 2 N regimes	1. Rampur, NP 2. Baireni, NP	Loam Clay	1999[3] 2002
R-W-mungbean rotation; permanent raised beds & CT; N rates and placement at sites 2 & 3; DSR & TPR at site 1	1. Ranighat, NP 2. Nashipur, BD 3. Rajshahi, BD	Clay loam Sandy loam Silt loam	1999[4] 2000[4] 2000
R-W rotation; CT & deep for R; CT & NT for W; TPR & DSR for R; SS & drill for W	Bhairahawa, NP	Silt	1997
R-W rotation; CT; ± straw mulch (3 rates)	Rampur, NP	Loam	2000
R-W rotation; CT; ± straw mulch & incorp. (3 rates)	Bhairahawa, NP	Silt	1998

[1] R=rice; W=wheat; NT=no-tillage; CT=conventional tillage; SS=surface seeding; TRP=transplanted rice; DSR=direct seeded rice
[2] NP=Nepal; BD=Bangladesh
[3] CT treatments were introduced in 2001 and expt. was R-W rotation until 2002
[4] Expt. at site1also had R-lentil rotation that was dropped in 2002 to include ± straw mulch in R-W rotation. Expt. at site 2 was modified in 2002 to include straw mulch (no without mulch treatment)

The experiments can only provide data for a few management practices and soil textures, but they will be important to validation of model results that will be used to more broadly characterize the effects of reduced tillage and residue management on SOC dynamics.

The only experiments with a complete no-tillage rice-wheat system are in the Nepal Terai. Two identical experiments compare conventional tillage (CT) with no-tillage (NT) and the effects of using straw mulch on loam and clay soils. They represent a no-tillage option for resource poor farmers without equipment. One experiment on a loam soil at the IAAS campus (Figure 7) is in the fourth crop cycle, and a second experiment on a clay soil in a nearby farmer field (Figure 9) was initiated with the 2002-03 wheat crop.

Mulch significantly increased yields of rice and wheat over the first 3 years of the experiment at Rampur, (Figure 7, upper left panel). In the third year, CT treatments were also

Figure 7. Tillage experiment at Rampur, Nepal

introduced by splitting the plots. Tillage increased the yield of wheat for both mulch treatments, still with a significant mulch effect (Figure 8, upper right panel). In 2002-03, there was no effect of tillage on wheat yield, and straw mulch significantly increased yield in the NT treatment. The results of this experiment reflect complex interactions involving tillage, soil-water relationships, weeds, and physical structure at the soil surface. Overall, they emphasize the importance of using mulch to maintain a good physical condition of surface soil with NT.

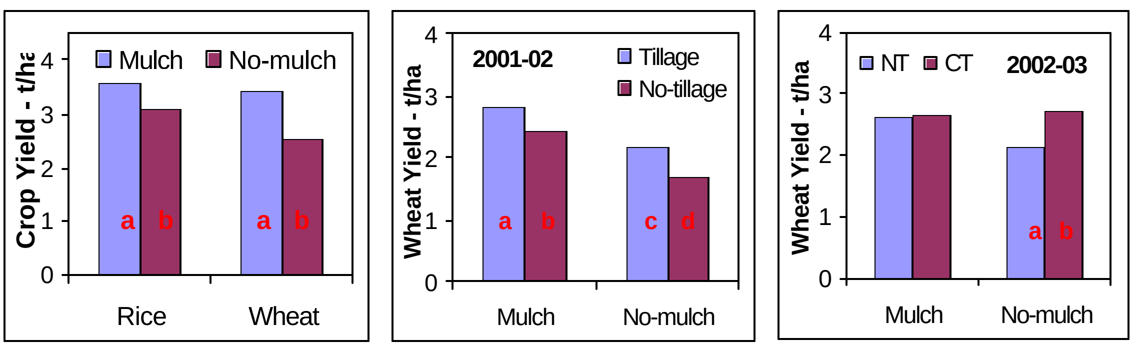

Figure 8. Effect of tillage and mulch on yields of rice and wheat over first three years (left panel) and effect of introducing tillage on wheat yields in the third and fourth years (middle and right panels) at Rampur, Nepal

The experiment on the clay soil at the Baireni farm site was established in 2002 and had some transition challenges. The two N fertilizer regimes performed poorly in the NT treatments and weed pressure was also significant, especially without mulch. This resulted in poorer growth of wheat in NT plots, and without mulch in both CT and NT treatments (compare the two extremes in the lower panels in Figure 9). Given these constraints, the yield of wheat was significantly higher in the CT compared to the NT treatments and with mulch for both tillage regimes (Figure 10).

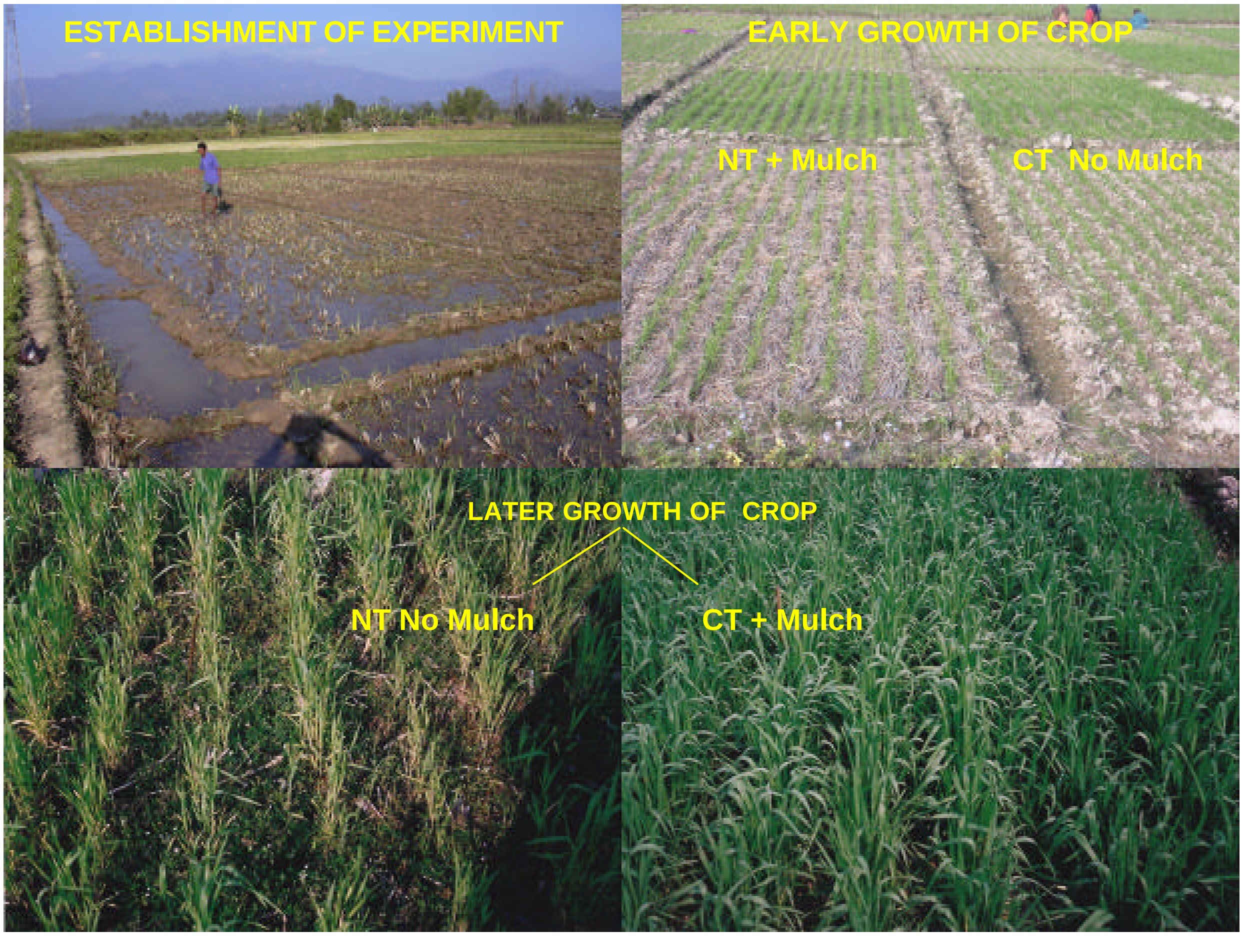

Figure 9. Stages of the tillage experiment at Baireni, Nepal

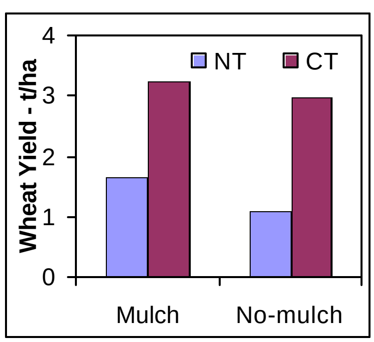

Figure 10. Effect of tillage and mulch treatments on wheat yield at Baireni, 2002-03

IV. Generation of ^{13}C Labelled Straw

Duplicate open topped chambers (Figure 11) at Khumaltar, Nepal were use to generate ^{13}C labelled straw of rice and wheat at doubled atmospheric CO_2 levels. Supplemental CO_2 from fossil fuel was provided using gas cylinders purchased from the Coca Cola company. Approximately 7 kg of dry straw was generated for both rice and wheat. The straws will be used in the tillage experiment at Rampur and the residue management experiment at Bhairahawa.

Figure 11. Open topped chamber used to label crops with ^{13}C

V. COLLABORATORS

A. Country

Country	Name	Discipline	Institution
Bangladesh	Baksh, M.E.	Agric. Economics	BARI
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Country	Name	Discipline	Institution
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Lauren, Dr. J.	Crop & Soil Science	Cornell Univ.
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C. Other Collaborating Institutions

Name	Discipline	Institution
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D. Graduate Students

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IAAS				