# Simulation and Analysis of Soil Organic Carbon Stock of Cornbased-Cropping Systems Under Conservation Agriculture in Claveria, Misamis Oriental, Philippines

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#### Abstract

**Objectives:** Characterizing soil organic carbon stock is important for comparing different management systems for sustainability and environmental quality. This study was conducted to perform simulation and analysis of long term soil organic carbon stock of corn-based cropping systems under conservation agriculture practice and plow-based system. Methods/Analysis: Field experiments were conducted in a typical upland agricultural area in Claveria, Misaims Oriental, and Philippines. Five experimental treatments in the form of cropping patterns that included Conservation Agriculture Production Systems (CAPS) and conventional plow-based system with two levels of fertilizer application as subplots were laid in a split plot design and replicated four times. Soil organic carbon stock monitoring at 0-5; 5-15 and 15-30 cm soil layers of the various plots was performed. The variability of soil organic carbon stock was analyzed using the Roth-C model for each of the CAPS treatments and plow-based system. Findings: The Soil Organic Carbon (SOC) stock at the uppermost soil layer increases exponentially under CAPS and declines steadily under plow-based system after 50 years of simulation. The best corn based cropping systems under the conservation agriculture practiced in terms of soil organic carbon stock proved to be those corn-cropping systems with cover crops that provide relatively high biomass such as the Stylosanthes guianensis. Novelty/Improvement: This study demonstrated that conservation agriculture has a positive impact on soil organic carbon stock as a result of minimum soil disturbance, continuous mulch cover and diversified crop rotation. Conversely, conventional plow-based systems negatively impact the soil quality and its long-term practice may lead to serious degradation of this important natural resource.

Keywords: Conventional Plow-Based System, Cropping Systems, Minimum Soil Disturbance, Roth-C Model, Soil Quality

### 1. Introduction

The Philippines is well-endowed with rich natural resources. Its agricultural land is very fertile and productive thus enabling farmers to plant different crops throughout the year. However, because of natural and human-induced factors, the incidence of land degradation particularly soil quality has become a prominent and recurring environmental problem. The United Nations Convention to Combat Desertification reported that about five (5) million hectares of upland agricultural areas are seriously degraded resulting to a 30%-60% reduction in soil productivity and water capacity.

The Soil Organic Carbon (SOC) is one of the primary indicators of soil quality. It is used to characterize sustainable management of the vital natural source which is soil. In<sup>1</sup> contended that "if we are to offer farmers a chance to survive on the farm and if sustainable and economically viable-agriculture is to be achieved, then the old paradigm of agricultural production and management

must be changed and Conservation Agriculture (CA) as a new farming practice must be implemented".

CA is a new paradigm in doing upland crop production. It is the application of biological engineering technology based on the principles of minimum soil disturbance, continuous mulch cover and diversified crop rotations<sup>2</sup>. This agricultural practice has already been adopted by numerous countries in the world and about 95.8 million hectares were found to be successful and sustainable. The application in Southeast Asia on the other hand is still at the research stage. As of now, few researches have been conducted on the appropriate Conservation Agriculture Production System (CAPS) in the Philippines considering the climate variability in the country. Hence, this study was conducted to address the questions which include the following; what kinds of crops and cover crops will be suited for local conditions for crop rotation and more importantly, how CAPS increase SOC.

The objective of the study is to perform simulation and analysis of the long term SOC stock of corn-based cropping systems under conservation agriculture and conventional plow-based system using the RothC-26.3 model.

One of the most promising techniques for the estimation of SOC stock is through mathematical modelling. Soil C models are primarily used as research tools to describe how management and environmental variables influence SOC, and to predict SOC stocks.

RothC is one of the most widely used and tested SOC models. It was tested based on long-term field experiments on a range of soils and climatic conditions in Western and Central Europe under various conditions and treatments<sup>3-6</sup>. In other parts of the world, the model was applied to the prediction of soil organic carbon stock on regional and national scales. Moreover<sup>2-10</sup> compared the performance of nine (9) leading SOM models using long- term data sets from seven (7) sites across a range of land uses, soil types, and climatic region. Accordingly, the model fell into a group of six (6) models performing significantly better than another group of three (3) models. Also<sup>11</sup> evaluated the suitability of the model for long term experiments on Japanese non-volcanic upland soils using six(6) long-term experimental data sets. It was concluded that the model has adequately simulated changes in the soil carbon content with time.

The version of RothC model, RothC-26.3, is derived from earlier versions developed by<sup>12</sup>. As described by, RothC model is used to quantify the turnover of carbon

in non-waterlogged topsoils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It was also developed to simulate the effects of agricultural management on the stocks of organic carbon. It was designed to operate in monthlytime steps, on a year to centuries-time scale, using soil C data to a depth of 23 cm. In applying the model the input plant material is split into the above and below ground residues including root exudates, into Decomposable Plant Material (DPM) and Resistant Plant Material (RPM), both of which accumulate at various times throughout a year. The ratio DPM/RPM is used directly in the model to allow for changes in the decomposability of the input from vegetation. The recommended DPM/RPM ratio for most agricultural crops and improved grassland is 1.44 and all incoming plant material passes through these two compartments once.

In<sup>13-14</sup> claimed that DPM and RPM are decomposed into microbial biomass (BIO) and Humified Organic Matter (HUM) and  $CO_2$  as gas emissions. Also, the proportion that goes to  $CO_2$  and to BIO + HUM is determined by the clay content of the soil. The BIO + HUMis then split into 46% BIO and 54% HUM. Subsequently both BIO and HUM further decompose to produce more  $CO_2$ , BIO and HUM (Figure 1). The model also recognizes a fifth, inert pool of organic matter (IOM). Inert organic carbon is characterized by<sup>2</sup> as passive pool of organic carbon whose decomposition occurs at a timescale of decade to thousands of years.



Figure 1. Structure of the Rothamsted carbon model.

With the exception of IOM, each compartment decomposes by first-order kinetics at its own characteristic rate. The actual decomposition rate is determined by

using modifiers for the soil moisture, temperature, and plant cover.

If an active compartment contains Yo (t C ha<sup>-1</sup>) this declines to Yo  $e^{-abckt}$  (t C ha<sup>-1</sup>) at the end of the month. Hence, the amount of the material in a compartment that decomposes in a particular month is given by equation (1).

 $Y = Yo \left( 1 - e^{-abckt} \right) \tag{1}$ 

where:

Yo	=	the initial amount of carbon in the					
		particular pool					
А	=	the rate modifying factor for temperature					
b	=	is the rate modifying factor for moisture					
с	=	is the soil cover rate modifying factor					
k	=	is the decomposition rate constant for					
		that compartment					
t	=	1 / 12, since k is based on a yearly					
		decomposition rate.					

## 2. Conceptual Framework

The RothC-26.3 model requires data input for climatic data, soil data, land use and land management data. The climatic data required for the model consisting of the monthly rainfall (mm), mean monthly air temperature (°C) and monthly pan evaporation (mm). The clay content is also required as the soil data input. The data input on land use and land management are guided with respect to the different treatments. On the other hand the annual soil organic matter input of the different treatments is also required in the simulation. The model are calibrated and validated by comparing the simulated SOC values and field experiment SOC values. The Nash-Sutcliffe model Efficiency (NSE) coefficient was used to assess the accuracy of the model outputs.

## 3. Materials and Methods

#### 3.1 Experimental Site and Design

The experimental site was established at the Sustainable Agriculture and Natural Resource Management (SANREM) research site in Claveria, Misamis Oriental, and Philippines in July 2010. The treatments were in the form of cropping patterns laid out in a split plot design in four replications. The main plot with an area of 20m x 60m served as agriculture and management system

practice consist of four (4) CAPS plots namely CAPS treatments T1 (*Arachis pintoi* + *Maize* – *Arachis pintoi*); T2 (*ArachisPintoi* + *Maize* – *Arachis pintoi*); T3 (*Maize* + *cowpea* - *upland rice*+ *cowpea*); and T4 (*Maize* + *rice bean* – *Maize* + *Rice Bean*) and one (1) conventional plow-based system (control) called treatment T5 (monoculture Maize – *Maize*) The sub-plots measuring 10m x 60m which served as fertilizer levels were F0 (120-60-60) and F1 (60-30-30) for N, P<sub>2</sub>O<sub>5</sub>K<sub>2</sub>O.

#### 3.2 Soil Sampling and Analysis

Soil sampling was performed in each of the CAPS treatments from 2010 to 2013. Both disturbed and undisturbed soil samples were collected in each plot and at both fertilizer level depths of 0-5cm, 5-15cm and 15-30cm. Composite soil sampling was performed seven times during the three year duration of the study. Undisturbed soil samples were collected for bulk density determination using the soil auger and core samplers with a diameter of 5cm and height of 5cm. The soil texture and bulk density were obtained through laboratory measurements using pipette and core method respectively. The Walkley-Black method was employed by the Analytical Laboratory, Agriculture and Science Cluster - University of the Philippines, Los Baños, (ASC-UPLB) Laguna for the SOC analysis.

# 3.3 Total Aboveground Biomass of the Main, Secondary and Cover Crops

The total above ground biomass produced by the main crop in the different treatments in 2011 was obtained from the ratio of their respective grain yield and harvest index. The total aboveground biomass was calculated using the equation (2) taken from.

$$4GB = \frac{GY}{HI} \tag{2}$$

where:

AGB = Total Above Ground Biomass (t  $ha^{-1}$ )

 $GY = Grain Yield (t ha^{-1})$ 

HI = Harvest Index

#### 3.4 Estimating Carbon Inputs from the Different Crops

In cropping systems, organic matter input into the soil depends on crop biomass produced and the fraction

that is integrated into the soil in the form of roots, root exudates, and crop residues. Since one of the basic principles of CAPS is no removal or no burning of crop residues, the above and below ground biomass are the major soil carbon sources.

For conventional plow-based system, harrowing by animal-drawn spike-toothed harrow was performed in addition to two times plowing, furrowing, off barring and hilling up activities. Harrowing will cause to drag all the aboveground residues to the sides of the farm, and leaving the field clear from any debris, and no stubble incorporation. The piles of residues at the sides of the farm were sometimes burned or just allowed to decompose.

The conversion coefficient to estimate the annual carbon inputs in ton C ha<sup>-1</sup> from various crop residues (above and below ground) is given in Table  $1^{15}$ .

Table 1.	Coefficients to calculate the carbon input
	from various sources of carbon

Coefficients	Rice <sup>1</sup>	Corn <sup>2</sup>	Pulses <sup>1</sup>	Green Manure <sup>1</sup>
Root: shoot ratio	0.1	0.2	0.1	-
Fraction of carbon in root biomass (kg C/kg root)	0.4	0.4	0.4	-
Fraction of carbon in straw biomass (kg C/kg of straw)	0.4	0.4	0.4	-
Carbon/GM biomass (kg C/kg of GM)	-	-	-	0.44
Carbon Fraction of leaf biomass (kg C/ kg of DM)	-	-	-	-
Carbon Fraction of stem and branch biomass (kg C/kg of DM)	-	_	-	-
Carbon Fraction of fibrous root biomass (kg C/kg of DM)	-	_	-	-
Carbon Fraction of storage root biomass (kg C/kg of DM)	-	-	-	-

\* Cowpea and rice bean are grain legumes and they belong to pulses group  $^{\underline{15}}$ 

#### 3.5 Model Calibration and Validation

The Roth C model can be used in two modes: First, the forward mode is used to simulate SOC under changed agricultural management and input of plant materials, second, the inverse mode is employed to calculate required plant inputs to reach the SOC content for equilibrium conditions with known land-use history. For calibration purposes, the model was used to run in inverse mode to determine the starting points for each SOC pool. It was assumed that the SOC of the uncleared site under grass cover had reached equilibrium before the start of the project or at the time of measurement of the initial SOC (2010).

The model was run iteratively under constant environmental conditions fitting carbon inputs to match the initial SOC stock thus, the distribution in compartments (DPM, RPM, BIO, HUM) with different decomposition rates. The data of carbon and radiocarbon ages in all these compartments received in equilibrium mode (initial soil state, initial radiocarbon ages) were used to run the model in short term mode. Model calibration was made using data observed in 2010 and 2011. Model validation of the calibrated model was performed by comparing the simulated values of SOC and observed values in 2012. The performance of the model was evaluated using Pearson correlation coefficient (r), Root-mean Square Ratio (RSR) and Nash-Sutcliffe coEfficient (NSE).

### 3.6 Model Simulation to Determine Long-term Soil Organic Carbon Stock

After the initial SOC had been established, simulating SOC was set for each treatment for 50 years beginning in 2011 and ending in 2060. Management files were created for each treatment while the input weather data which serves as weather files were use constant for the simulation period.

# 4. Results and Discussion

### 4.1 Soil organic Matter among CAPS Treatments

The SOM in % were observed at 0-5 cm, 5-15cm and 15-30 cm layers of the soil after two, three, four and six cropping of maize. At the 0-5cm soil layer, significant differences

in SOM content among treatments were observed after two maize cropping seasons. Regardless of fertilizer level, CAPS treatment T4 showed higher SOM as compared to the other CAPS treatments (T1, T2, T3) including the plow-based treatment (T5). The variability of SOM among the CAPS treatments can be attributed to the differences in the cropping systems and the different amounts of crop residue inputs. This agrees with the report of that SOM accumulation depends on the amount of C inputs.

Similar source of variation was also observed after the third up to sixth cropping of maize. However, none among the CAPS treatments varied in terms of SOM. Apparently, all CAPS are significantly higher in SOM content than in the plow-based system regardless of the level of fertilizer. An interaction between agricultural practices and level of fertilizer was observed after the fourth and sixth cropping of maize. However, none among the treatments on the level of fertilizer at each level of agricultural practice varied in SOM. The result obtained after the third cropping up to sixth cropping of maize is consistent with the findings of his 5-year study on the effects of various management factors on organic matter accumulation in 0.6 in (15mm) of soil with no tillage as the primary prerequisite, revealed that increasing the amount of crop residue left was a major factor in increasing the organic matter in this layer. Also, West and Post (2002) found that transitioning to more complex crop rotation can increase soil organic matter.

At the 5-15cm and 15-30cm layers of soil, significant variability's among treatments were observed at 5% probability after the sixth cropping of maize. All CAPS treatment exhibited remarkably higher SOM than the plow-based system. An improvement of SOM at the middle and deeper layer of soil after three (3) consecutive years of CAPS practice was also observed. In conservation agriculture, more attractive habitats for increased soil organism populations and activity were developed due to minimum disturbance of burrows and living chambers with an almost continuous food supply. This is probably the reason for the improved SOM in the middle (5-15cm) and deeper layer (15-30cm) after six cropping of maize.

#### 4.2 Simulation and Analysis of Soil Organic Carbon

*Soil input data* Modelling SOC focused on the uppermost soil layer at 0-5cm since this is the layer that exhibited the most significant temporal changes in SOM. In preparation

for model calibration and validation, soil data obtained in 2010 and 2011 were analyzed. The soil is clayey type(76.2% clay), and the initial SOC stock was estimated to be 17.5 (t C ha<sup>-1</sup>). The estimated SOC stock in 2011 under each of the five treatments is shown in Table 2.

Table 2.	Estimated soil organic carbon from soil
	sampling in 2011

Treatment	Soil Organic Carbon (t C ha <sup>-1</sup> )			
Ireatment	F0	F1		
T1	17.83	17.20		
Τ2	18.40	17.12		
Т3	17.50	16.80		
Τ4	19.20	18.40		
Τ5	16.94	16.90		

*Climatic input data.* A constant climatic condition was assumed in this modeling study. The average monthly rainfall and temperature values were based on observed data from 2002 to 2013, while average evaporation was based on the data collected from 2009 to 2013 at the weather station in Misamis Oriental State College of Agriculture and Technology (MOSCAT), Claveria, Misamis Oriental, Philippines. The average monthly rainfall was highest during the month of September at 370.4 mm and lowest during the month of March at 115.2 mm. The monthly evaporation ranged from 84.7 mm in March to 91.4 mm in January. The average monthly temperature was highest during the month of May at 25.01°C and lowest during the month of February at 23.7°C.

Land use and land management. Prior to the implementation of the research project, typical native vegetation such as cogon (*Imperata cylindrical*), tigbaw (*Saccharum spontanium*), dinog (*Antidesma ghaesembilla* Gaertn.) and other grasses and shrubs generally covered the landscape.

The choice for land use and management practice under CAPS treatment was guided by the basic principles of conservation agriculture. The area under CAPS was assumed to be covered throughout the year while the area under the plow-based system was considered fallow two months after harvesting the maize second crop and during months of land preparation on both maize cropping.

Annual residue input. In preparation for model calibration and validation, annual soil carbon inputs from above ground and below ground residues were estimated for various CAPS treatments and conventional plow-based system. Results of this estimation for year 2011 and 2012 are shown in Table 3 and 4, respectively.

#### 4.3 Model Calibration

The Roth C model was calibrated using 2010 and 2011 data. Results of model calibration in Figures 2 and 3 showed that there is satisfactory agreement between the simulated and measured data during model calibration for all treatments regardless of fertilizer level. The respective values of model evaluation statistics for F0 and F1 during model calibration in 2011 are 0.80 and 0.76 for R<sup>2</sup>, 0.68 and 0.64 for RSR and 0.54 and 0.59 for NSE, respectively.

#### 4.4 Model Validation

The Roth C model was then validated using the 2012 data (Figures 4 and 5). Results of model validation showed that there is satisfactory agreement between simulated and observed values with NSE of 0.73 and 0.54 to F0 and F1 respectively.

#### 4.5 Model Simulation and Analysis of Soil Organic Carbon Stock

Results of the simulation of SOC at the uppermost soil layer of 0-5cm at various CAPS treatments including the conventional farming treatment for 50 years is shown

Table 3.Estimated carbon inputs (t C ha-1) from above and below ground residues at various treatments for year2011

	Annual Residue Input						
Treatment		FO		F1			
	maize	Cover/ Legume crops	Total	Maize	Cover/ Legume crops	Total	
T1	3.59	1.67	5.27	1.75	1.78	3.54	
T2	3.85	1.20	5.06	3.72	0.85	4.57	
Т3	3.09	0.86	3.95	1.66	1.20	2.86	
T4	4.91	0.25	5.66	4.03	1.20	5.23	
T5	1.23	0.00	1.23	1.14	0.00	1.14	

 Table 4.
 Estimated carbon inputs (t C ha<sup>-1</sup>) from above and below ground residues at various treatments for year 2012

	Annual Residue Inputs					
Treatment	F0			F1		
	Maize	Cover/ Legume crops	Total	Maize	Cover/ Legume crops	Total
T1	9.73	3.20	12.93	8.75	2.87	11.63
T2	7.05	4.91	11.96	6.48	4.51	10.99
T3	5.21	1.06	6.27	4.58	1.00	5.58
T4	5.77	2.37	8.14	5.38	2.85	8.24
T5	3.30	0.00	3.30	3.13	0.00	3.13



**Figure 2.** Measured vs. Simulated SOC at various CAPS treatments at F0 during model calibration.



**Figure 3.** Measured *vs.* simulated SOC at various CAP treatments at F1 during model calibration.



Figure 4 Measured vs. simulated SOC at various CAPS treatments at F0 during model validation.



**Figure 5.** Measured *vs.* simulated SOC at various CAPS treatments at F0 during model validation.

in Figures 6 and 7 for the two fertilizer levels F0 and F1, respectively. The simulated soil organic carbon content increased exponentially over time in all CAPS treatments regardless of fertility level. Results indicate that T2 exhibited the highest SOC stock followed by T1, T4 and T3 while conventional plow-based system exhibited steadily declining trends overtime.



**Figure 6.** Simulated SOC (t C ha<sup>-1</sup>) at F0 for 50 years at CAPS treatments.

The increase in SOC stock under CAPS treatments may be attributed to the compounded impact of the continuous practice of minimum soil disturbance, diversified cropping system and crop residue returned to



**Figure 7.** Simulated SOC (t C ha<sup>-1</sup>) at F1 for 50 years at CAPS treatments

the soil. The model also reflected the deteriorating SOC stock when a conventional farming system is continuously adopted. This may be attributed to the negative effects of continuous soil disturbance and minimum biomass input to the soil under conventional plow-based system. Also, the reduction in SOC has commonly been attributed to the removal of much of the aboveground plant biomass produced and intensive tillage accelerates the loss of C from the soil by microbial respiration and  $erosion^{16-17}$ . The results of this modeling study agree well with the earlier research findings. In<sup>13</sup> showed that the change in SOM is linearly related to the level of carbon inputs in each of seven long-term experiments when the change in C was averaged across the duration of the experiment. In<sup>18-19</sup> studied different tillage systems for 19 years and revealed that properties of soil were affected significantly after a long period of time of operations because of the accumulations of residues from the reduced tillage than the conventional tillage. However, model simulation results pose some uncertainties due to the following: the carbon inputs from crop residues were simply estimated. These carbon input data were calculated according to the published value of coefficient for the conversion of carbon from various biomass input. To increase the accuracy of model simulation results, input from crop residues should be measured and more biomass data should be gathered.

## 5. Conclusion

Long-term simulation of SOC stock at 0-5 cm soil layer indicated that SOC increases exponentially over time in all CAPS treatments with T2 exhibiting the highest SOC stock followed by T1, T4 and T3regardless of fertilizer levels. On the other hand, model simulation showed that the SOC stock under conventional plow-based system decreases over time in both fertilizer levels.

This study concludes that conservation agriculture generally increased soil organic carbon stock, while conventional plow-based system generally degrades the quality of this important natural resource especially at the uppermost layer. The best CAPS treatments include those with cover crops that provide greater biomass such as Stylosanthes guianensis. Furthermore, the RothC model proved to be applicable in performing long-term prediction of soil organic carbon at the uppermost layer for both conservation agriculture production systems and conventional plow-based system in the Philippines. Furthermore, the result of this study can already serve as basis for policy formulation and potential upscaling of conservation agriculture in other upland areas in the Philippines as a soil conservation measure for sustainable upland crop production.

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