International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July

Ref: C0450

Conservation agriculture and tillage effects on soil organic matter and residual moisture content in selected upland crop production systems in the Philippines

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Abstract

This study aimed to analyze the influence of conservation agriculture and tillage on soil organic matter and residual moisture content in selected upland crop production systems in the Philippines. Conservation agriculture is based on the principles of minimum soil disturbance, continuous mulch cover and diversified species rotation. Six Conservation Agriculture Production Systems (CAPS) treatments in the form of cropping patterns with different cover crops under two fertility levels including plow-based or tilled system serving as control were established and laid out in a randomized complete block design in a typical upland agricultural producing area in southern Philippines. Composite soil samples were collected at the uppermost soil layer with a depth of 0-5 cm and were analyzed for soil organic matter content. The residual soil moisture content was also measured at the various plots of the CAPS treatments using time domain reflectometry (TDR). Results showed that the soil organic matter for all CAPS treatments (T1 to T5) was generally higher than under T6 (plow-based) after three years of cropping. After three cropping seasons, treatment T2 (Maize+stylosanthes guianensis-stylosanthes guianensis-fallow) exhibited the highest soil organic matter at the uppermost soil layer (0-5 cm). Linear regression analysis showed that the soil organic matter at the uppermost soil layer under plow-based system declined over time for both fertility levels. Under a high fertility level, the soil organic matter at the uppermost layer for all CAPS treatments T1 to T5 all exhibited a positive change over time, with T2 (Maize+stylosanthes guianensis-stylosanthes guianensis-fallow) exhibiting the highest rate of increase. Under a moderate fertility level, the soil organic matter for CAPS treatments increased over time with T5 (cassava+Stylosanthes guianensis) exhibiting the highest rate of increase. Analysis of variance of the residual moisture after one, two and three cropping seasons showed that the plots under conservation agriculture have significantly higher residual moisture content than under plow-based system with CAPS treatment T2 exhibiting the highest residual moisture content. Results of this study suggest that conservation agriculture has a positive impact on soil quality in terms of soil organic matter and residual moisture content while tillage systems negatively impact these soil quality parameters.

Keywords: soil quality, conservation agriculture, tillage, soil organic matter, residual moisture content

1 Introduction

The sustainability of upland crop production systems depends to a large extent on soil quality among other factors. Soil quality in crop production areas is generally influenced by the nature of the farming system being employed. In many parts of the Philippines, conventional plow-based system continues to be practiced. This consequently leads to serious soil degradation due to significant soil disturbances induced by this traditional practice. Soil disturbances due to plowing lead to the eventual loss of soil organic matter due to greater exposure of the soil particles to microbial attack. The loosening of the soil particles under plow-based system may also influence the residual moisture retention capacity of the soil. Furthermore, from the economic standpoint, this traditional plow-based system leads to increase in cost of agricultural crop production due to increased fertilizer inputs, soil amendments and other inputs to compensate for the loss of soil fertility and the degradation of soil quality. From the environmental protection standpoint, this traditional agricultural practice leads to excessive soil erosion and sedimentation of natural streams, reduction in channel capacities and flooding. This adverse impact has become even more pronounced in the recent years with the occurrence of extreme rainfall events presumably due to climate change and climate variability.

A new paradigm in doing upland crop production is the application of a biological engineering technology called “conservation agriculture”. Conservation agriculture is based on the principles of minimum soil disturbance, continuous mulch cover and diversified crop rotations (Erenstein et al., 2008). It has been widely adopted in countries like the United States, Canada, Brazil, Argentina, Australia, Paraguay and on the Indo Gangetic Plains, on about 95.8 million hectares (Derpsch, 2008), as a sustainable agriculture and soil conservation practice.

In Southeast Asia, the application of conservation agriculture is still essentially at the research stage. One of the most notable of these is in Cambodia, where conservation agriculture has been tested in numerous farms. Presently it is the subject of continuing research (Boulakia et al., 2009). In Laos, Tivet et al. (2008) demonstrated that soil aggregation, water holding capacity and biological activity were enhanced under conservation agriculture production systems. In Vietnam, conservation agriculture on sloping lands was found to reduce soil erosion by up to 96% and at the same time increased crop yield by over 200% (Doanh and Tuan, 2008). Lienhard et al (2013) examined the microbial abundance and biodiversity under conservation agriculture and tillage systems in Laos as a measure of soil health and is the subject of continuing research. Other than the aforementioned, no other published literature is available pointing towards significant advances in conservation agriculture research in Southeast Asia.

In the Philippines, no research has been done on the soil quality impacts of conservation agriculture, in the strictest sense. Hence, this study was conducted to analyze the impact of both conservation agriculture and conventional plow-based system on soil quality. In particular, the objective of this study is to analyze the effect of conservation agriculture and tillage on soil organic matter and residual moisture content in selected crop production systems in the Philippines. Ultimately, this study aims to generate new knowledge and empirical evidence on the soil quality impacts of these farming systems to serve as basis for potential upscaling of conservation agriculture in upland crop production areas in the Philippines.

2 Materials and methods

This study was conducted at the Sustainable Agriculture and Natural Resources Management (SANREM) research site in Claveria, Misamis Oriental, Philippines. Six CAPS treatments in the form of cropping patterns with different cover crops including plow-based system serving as the control were established and replicated four times and were laid out in a randomized complete block design in a typical upland agricultural producing area in the said

site. Subplots in each treatment were also established to represent two fertility levels. A summary of the experimental treatments is given in Tables 1 and 2.

Soil sampling was performed at the uppermost soil layer with a depth of 0-5 cm since this is the layer that is most sensitive to changes in soil organic matter. In view of cost limitations, composite soil sampling was performed for each treatment, i.e. several soil samples from each of the four replicates of each treatment were collected and mixed to represent a sample for the treatment dealt with. The soil samples collected were then brought to University of the Philippines Los Baños for laboratory analysis. The observed values of soil organic matter at various CAPS treatments were consequently analyzed.

The residual soil moisture content was measured using time domain reflectometry (TDR) after each cropping season. The TDR measurement of the residual soil moisture was made at the upper 12 cm to maximize the length of the available TDR probe and at the same time represent the soil layer with maximum root activity. To generate a more representative value of residual moisture content for each treatment, each plot was subdivided into four quadrants and TDR measurement was done in each. In each quadrant the average of three TDR readings was used to represent the quadrant. The average of the four quadrant readings was then used to represent the residual moisture for that plot or replicate for each of the six treatments. Analysis of variance of the residual moisture content was consequently performed.

Table 1. Summary of the CAPS treatments

	Cropping pattern
T1	Arachis Pintoi + Maize- Arachis pintoi + Maize
T2	Maize + Stylo - Stylo fallow
T3	Maize+cowpea - Upland rice +cowpea
T4	Maize+Rice bean-Maize+Rice bean
T5	Cassava + Stylo
T6	Maize-maize (conventional plow-based) (control)

Table 2. Summary of subplots

	Fertility Level
Fo	120-60-60 for N, P_2O_5, K_2O
F1	60-30-30 for N, P_2O_5, K_2O

3 Results and Discussion

Effect of the CAPS Treatments on Soil Organic Matter

Results of soil organic matter measurement at the uppermost soil layer of 0 to 5 cm at the various CAPS treatments performed after one, two and three cropping seasons are depicted graphically in Figures 1 and 2 for the two fertility levels Fo and F1, respectively. It is apparent that the upper layer soil organic matter content under plow-based system (Treatment 6) steadily declined over time while that under conservation agriculture production systems (Treatments 1 to 5) generally did not exhibit any substantial decline over time regardless of fertility level. In fact, all CAPS treatments except T1 showed a slight increase in soil organic matter after three cropping seasons.

To better assess the temporal variation of soil organic matter at the various CAPS treatments, linear regression analysis was performed for all observed data through the years.

Results of the regression analysis for the SOM at 0-5 cm soil depth for various CAPS treatments at both fertility levels are summarized in Tables 3 and 4. Based on the results, it is apparent that the soil organic matter at the uppermost soil layer under plow-based system is negatively correlated with time since the first cropping season with a moderately acceptable explained variance of 0.46 and 0,5 for fertility levels Fo and F1, respectively. Under fertility level Fo, the soil organic matter at the uppermost layer for all CAPS treatments T1 to T5 all exhibited a positive change over time, with T2 (maize+stylo) exhibiting the highest rate of increase. Under fertility level F1, the soil organic matter for CAPS treatments increased over time except for T1 and T3, with T5 exhibiting the highest rate of increase.

Although long term monitoring of soil organic matter may be necessary, the foregoing results already suggest that conservation agriculture has a positive impact on improving soil quality in terms of soil organic matter while plow-based system negatively impacts the soil. This finding may be attributed to the fact that the cover crops grown under conservation agriculture production systems, which are allowed to decay after each cropping, greatly contribute to increased soil organic matter. Moreover, the minimal disturbance of the soil under conservation agriculture production systems prevents the exposure of the soil particles to microbial attack thereby minimizing the loss of organic matter. Under a plow-based system, these conditions are non-existent and hence a continuous decrease in soil organic matter can be expected under this traditional farming system.

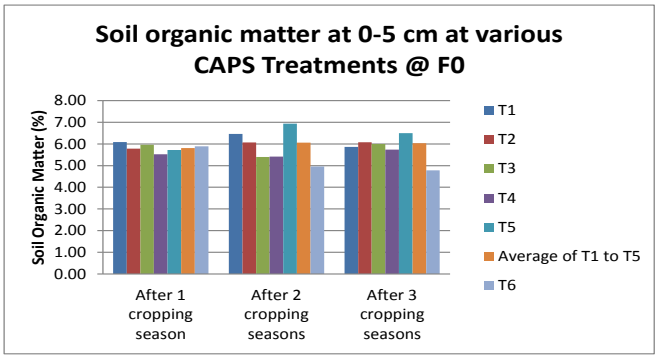

Figure 1. Soil organic matter at 0-5 cm at various CAPS treatments at fertility level Fo.

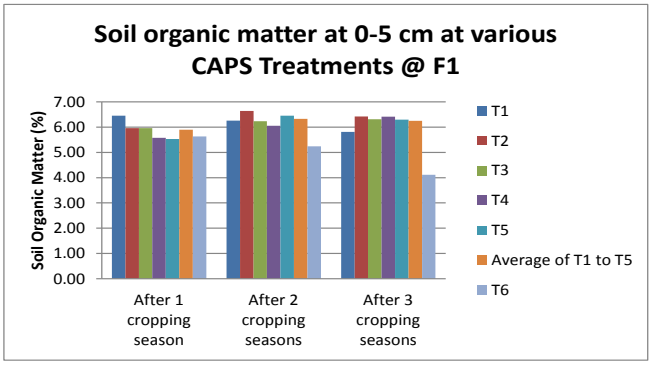

Figure 2. Soil organic matter at 0-5 cm at various CAPS treatments at fertility level F1.

Table 3. Summary of regression analysis for soil organic matter at 0-5 cm for all CAPS treatments at Fo.

Treatment	Regression Equation	R^2
T1	y = 8E-05x + 6.2278	0.006
T2	y = 0.0028x + 5.6285	0.573
T3	y = 0.0008x + 5.583	0.275
T4	y = 0.0004x + 5.4106	0.365
T5	y = 0.0004x + 6.2309	0.051
T6	y = -0.0012x + 5.6129	0.455

Table 4. Summary of regression analysis for soil organic matter at 0-5 cm for all CAPS treatments at F1.

Treatment	Regression Equation	R^2
T1	y = -0.0013x + 6.441	0.875
T2	y = 0.001x + 6.1215	0.666
T3	y = -0.0024x + 6.8338	0.377
T4	y = 0.0021x + 5.8558	0.495
T5	y = 0.0026x + 5.4825	0.885
T6	y = -0.0017x + 5.5632	0.504

Effect of the CAPS Treatments on Residual Moisture Content

Results of the TDR measurement of residual soil moisture content at the upper 12 cm of the soil at the various CAPS treatments after one, two and three cropping seasons are shown in Figures 3 to 5. It is apparent that the residual moisture content under conservation agriculture is generally higher than under plow-based system in each of the three samplings made. After one cropping season, the residual moisture content ranged from 30.6 to 39% on a volume basis for the CAPS treatments 1 to 5 and from 24.7 to 31.1 % for the conventional plow-based system. After two and three cropping seasons, the volumetric residual moisture contents varied from 20.7 to 25.1% and from 27.0 to 34.6%, respectively. On the other hand, the residual moisture content under plow-based system averaged 18.2 and 19.7% after two and three cropping seasons, respectively.

Analysis of variance using Dunnett's two-sided tests showed that the mean residual moisture content under each of the CAPS treatments 1 to 5 is significantly higher than that under the conventional plow-based system (α=5%). Results also showed that treatment 2 (maize+stylo-stylo fallow) yielded the highest residual moisture content followed by treatments 5, 1, 4 and 3.

The foregoing results suggest that conservation agriculture has a positive impact on improving the water retention capacity of the soil. Conversely, a plow-based system significantly reduces the soil water retention. Consequently, more water is conserved under conservation agriculture production systems than under a plow-based system. This has practical implications in terms of the timing of the next cropping and on irrigation frequencies.

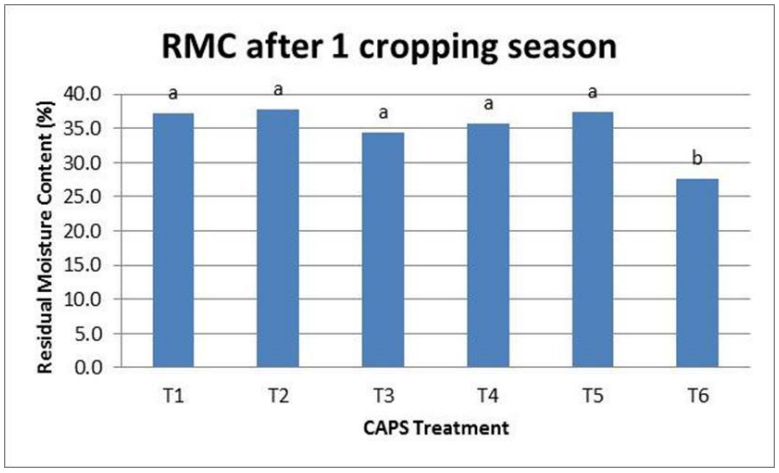

Figure 3. TDR-measured residual moisture content at various CAPS treatments after one cropping season.

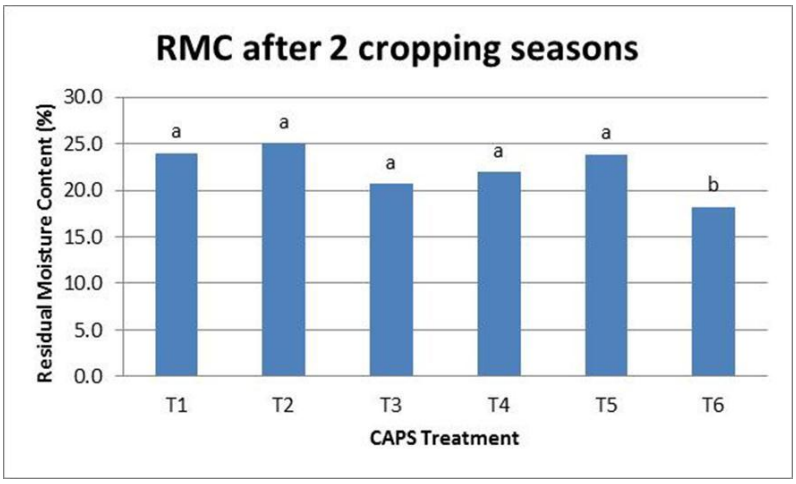

Figure 4. TDR-measured residual moisture content at various CAPS treatments after two cropping seasons.

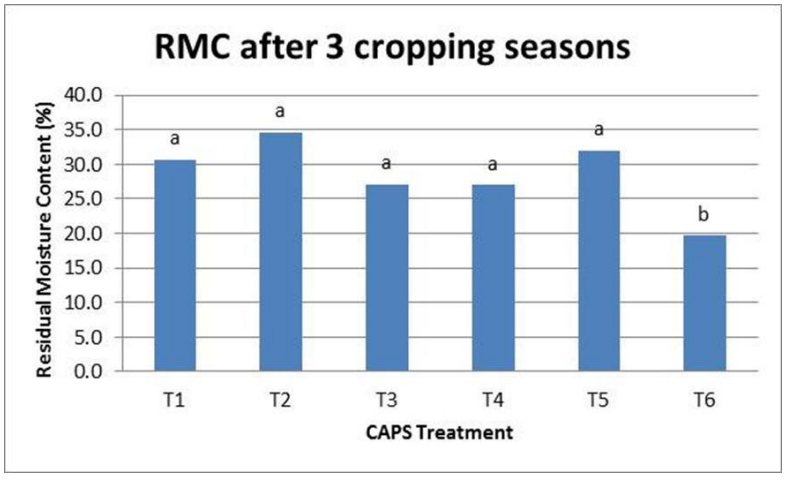

Figure 5. TDR-measured residual moisture content at various CAPS treatments after three cropping seasons.

4 Summary and Conclusions

This study was conducted to analyze the influence of conservation agriculture and tillage on soil organic matter and residual moisture content in selected upland crop production systems in the Philippines. Six Conservation Agriculture Production Systems (CAPS) treatments in the form of cropping patterns with different cover crops under two fertility levels including plow-based or tilled system serving as control were established and laid out in a randomized complete block design in a typical upland agricultural producing area in Claveria, Misamis Oriental, Philippines. Composite soil samples were collected at the uppermost soil layer of 0 to 5 cm from each of the six CAPS treatments for three cropping years and were analyzed for soil organic matter content. The residual soil moisture content was also measured at the various plots of the CAPS treatments using time domain reflectometry (TDR).

Results showed that the soil organic matter for all CAPS treatments (T1 to T5) was generally higher than under T6 (plow-based) after three years of cropping. After three cropping seasons, treatment T2 (Maize+stylosanthes guianensis-stylosanthes guianensis-fallow) exhibited the highest soil organic matter at the uppermost soil layer (0-5 cm). Linear regression analysis showed that the soil organic matter at the uppermost soil layer under plow-based system declined over time for both fertility levels. Under a high fertility level, the soil organic matter at the uppermost layer for all CAPS treatments T1 to T5 all exhibited a positive change over time, with T2 (Maize+stylosanthes guianensis-stylosanthes guianensis-fallow) exhibiting the highest rate of increase. Under a moderate fertility level, the soil organic matter for CAPS treatments increased over time with T5 (cassava+Stylosanthes guianensis) exhibiting the highest rate of increase. Analysis of variance of the residual moisture after one, two and three cropping seasons showed that the plots under conservation agriculture have significantly higher residual moisture content than under plow-based system with CAPS treatment T2 exhibiting the highest residual moisture content value.

Results of this study suggest that conservation agriculture has positive impact on soil quality improvement in terms of soil organic matter and residual moisture content while tillage systems negatively impact the soil in terms of these parameters. Nevertheless, continuous soil quality monitoring is necessary to generate additional empirical evidence on the impact of conservation agriculture and tillage on soil quality. Ultimately, all these findings could serve as basis for potential upscaling and policy formulation for soil resources conservation and sustainable agriculture in the Philippines.

5 Acknowledgements

This study is part of the USAID-funded SANREM-CRSP project on Conservation Agriculture for Food Security in Cambodia and the Philippines.

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