Original Research Article

Dynamics of Soil Carbon, Nitrogen and Soil Respiration in Famer's Field with Conservation Agriculture, Siem Reap, Cambodia

ABSTRACT

The years of intensive tillage in many countries, including Cambodia have caused significant decline in agriculture's natural resources that could threaten the future of agricultural production and sustainability worldwide. Long-term tillage system and site-specific crop management can affect changes in soil properties and processes, so there is a critical need for a better and comprehensive process-level understanding of differential effects of tillage systems and crop management on the direction and magnitude of changes in soil carbon storage and other soil properties. A study was conducted in farmer's field to evaluate the effect of conservation agriculture (CA) and conventional tillage (CT) on soil carbon, nitrogen and soil respiration in three villages of Siem Reap, Cambodia. Soil organic carbon ($p \leq 0.01$), soil total nitrogen ($p \leq 0.01$) and soil respiration ($p \leq 0.10$) for at least in two villages were significantly affected by tillage management. The soil quality was improved in villages with CA compared with villages with CT by increasing soil organic carbon (10.2 to 13.3 Mg ha^{-1}) and soil nitrogen (0.87 to 1.11 Mg ha^{-1}) because of much higher soil moisture (15.7±8.6 to 20.0±11.9%) retained in CA and with reduced soil temperature (30.4±2.0 to 32.4±2.3^{o}C) during the dry period. Additionally, field soil respiration was higher in CA (55.9±4.8 kg CO_2-C ha^{-1} day^{-1}) than in CT (36.2±13.5 kg CO_2-C ha^{-1} day^{-1}), which indicates more microbial activity and increased mineralization of soil organic carbon for nutrient release. The soil's functions of supporting plant growth and sink of carbon and recycler of nutrients was likely improved in agroecosystem with CA than in system with CT. Our results have suggested that CA may have had enhanced soils' carbon and nitrogen contents, nutrient supplying capacity and microclimate for soil microorganisms in three villages with vegetable production.

Key Words: Soil Carbon, Soil Nitrogen, Soil Respiration, Conservation Agriculture, Cambodia

1. INTRODUCTION

Long-term tillage system and crop management can affect changes in soil properties and processes. These changes can, in turn affect the delivery of ecosystem services, including climate regulation through carbon sequestration and greenhouse gas emission, regulation and provision of water through soil physical, chemical and biological properties [1, 2, 3]. Soil quality or soil health is the capacity of soil to function within ecosystem boundaries to support plants and animals and their health, resist erosion, and maintain environmental quality [4, 5]. It has been claimed that components of conservation agriculture (CA) promote soil health, productive capacity, and ecosystem services [6]. There is clear evidence that topsoil organic matter increases with conservation agriculture and with other soil properties and processes that reduce erosion and runoff and increase water quality. Reduction of erosion and runoff in system with CA or no-till system is due to protection of the soil surface with residue retention and increased in water infiltration [7]. Previous literature on soil carbon stocks has often discussed effects of tillage, crop rotations and residue management separately [8]. It is important to recognize that these components interact. These complex and multiple interactions will ultimately determine the potential for soil organic carbon storage especially in system with CA.

Conservation agriculture is a concept of crop production that aims to save resources, strives to achieve acceptable profits with high and sustained production levels, while at the same time conserving the environment [6, 9, 10, 11, 12]. Conservation agriculture involves a set of complex knowledge, intensive, and often counter-intuitive and unrecognized elements that promote soil health, and improve productive capacity and ecosystem services [6]. The three main principles of CA are the following: (a) soils are not disturbed more than 15 cm in width or 25%, whichever is lesser, of the cropped area and with no periodic tillage; (b) more than 30% of the soil is to be covered with crop residue or organic mulches at planting; and (c) crop rotation that involves at least three different crops [6, 9, 13, 14, 15]. In contrast, CT encompasses a multitude of objectives, which includes soil loosening, leveling of soil for seed bed preparation, mixing of fertilizers into soil, mineralization of soil nutrients, weed control, and crop residue management [14]. While tillage has been recognized to be beneficial to farmers, it is believed to come with cost to the farmers themselves, the environment, and natural resource base that is depended upon by farming [14]. The rapid decline in soil organic matter caused by tillage results in mineralization of nutrients for plant use [6], with significant source of carbon emissions [16], but it also leads to soil crust formation, soil compaction and reduction in water infiltration leading to high potentials of soil erosion [15, 17]. This calls for a new paradigm of sustainable agricultural production that balances increase food production with conservation and enhancement of natural resources. Stakeholders are now demanding a sustainable agricultural system that addresses issues about rising food, energy, and environmental costs [6, 11, 12].

Agricultural soils are important contribution to greenhouse gas emissions and the size of this contribution can be influenced by tillage practice and crop management [17, 18]. No-till system may promote N_2O emissions [17, 18, 19]. Leibig et al. [19] reported higher CO_2 emissions from 5 to 6 year old no-till soils than in soils with CT under sorghum and soybean rotations. Conversely, Dao [20] determined soil CO_2 flux following wheat in the 11th year of a tillage study and found the cumulative CO_2 evolved from soil was much higher for moldboard plowing than for no-tillage. Bauer et al. [21] also reported soil CO_2 flux was generally greater in conventional tillage than in conservation tillage after 25 years. Recently, Babujia et al. [22] reported that CT had greater CO_2 soil-atmosphere fluxes than no-tillage and other tillage systems.

The years of intensive tillage in many countries, including Cambodia have caused significant decline in agriculture's natural resources that could threaten the future of agricultural production and sustainability worldwide [11]. Hence, there is a critical need for a better and comprehensive process-level understanding of differential effects of tillage systems and crop management on the direction and magnitude of changes in soil carbon storage and other soil properties [17]. Additional information that are essential for determining where and why CT and/or CA does work in delivering different ecosystem services while increasing crop production are still needed. It is also important to establish strategically experimental sites that compare CA and CT on a range of soil-climate types. With this knowledge, greater progress can be made to fully understand the interactive effect of tillage system and crop management in enhancing soil health, soil quality and soil carbon storage. The objective of our field research was to compare the effects of CA and CT in terms of the soil organic carbon dynamics, total nitrogen, soil respiration, and other field soil quality attributes under vegetable production in three villages of Siem Reap, Cambodia.

2. MATERIALS AND METHODS

2.1 Site description and Site Preparation

The geographic location of the study sites is shown in Figure 1. Briefly, the 15 study sites were located in three villages in Siem Reap Cambodia: O'Village (13°19'22.9"N; 103°56'50.62"E); Sratkat village (13°20'55.57"N; 104°02'45.11" E); and Soutrikum Village (13°16'48.66"N; 104°07'47.85"E). The major soil types in the villages were similar to that of the Arenosols, prey Khmer Soil Group, FAO soil classification, as described by Seng et al. [23], equivalent to Soil Order Entisol and Suborder Psamments according to the USDA soil classification [24]. The soil properties include having a low organic carbon (0.5 g kg^{-1}), low total organic N (0.5 g kg^{-1}) with 73% sand, 22% silt and 5% clay, low CEC, exchangeable K, and Olsen P with high hydraulic conductivity [23]. Additionally, other soil properties are included in Table 1.

Cambodia has two distinct seasons, marked with dry and wet conditions. Averaged over several decades (1900–2009), Cambodia has an annual rainfall of 1837 mm and annual mean temperature of 26.5°C (The World Bank Group, 2015). A critical period of crop production was identified which falls on the months of April to July, referred to as the early wet season, due to erratic rainfall patterns [23] with high temperature (Figure 2).

In CT, the soil was continuously tilled at about 20 cm depth, using hoe and moldboard plow drafted by two buffalos. The soils were then evened out using rakes, beds remade, remaining residues taken out and sometimes burned, and holes manually dug for the next crop (Figure 3). In CA, tillage was no longer repeated after the first crop production, dry rice straws (*Oryza sativa* L.) of about 15 Mg ha^{-1} were placed on top of the vegetable beds' surface as mulch (8 cm height). A cover crop *Crotolaria juncea* L. was planted at 0.5 m apart at a rate of 30 kg ha^{-1} between rows of crops. One week prior to harvesting the main crop, *Crotolaria juncea*, was then cut from the base of the stem, laid on top of the soil, and covered with rice mulch with the same rate as above. Holes were dug at about 10 cm in diameter and by 10–12 cm depth for planting the next crop.

The experiment was laid out in randomized complete block design. Each farmer's plot was divided into four sections and was randomly assigned with treatments CA and CT. Each treatment was replicated five times. Crop history and/or different crop rotations for the three villages during the study period are presented in Table 2.

2.2 Soil sampling and sample preparation for laboratory analyses

This experiment involved laboratory and field tests. For the laboratory part, there were nine farms selected, three farms within each of the three villages (O' village and Sratkat village in Prasat Bakong District and Soutrnikum village, Trabek District). Within each farm, CA and

CT experimental units covering an area of about 25 m^2 were sampled. Soil samples were collected diagonally from both CA and CT plots in 2 depths (surface 0-10 cm and bottom 10-20 cm) using a stainless steel trowel as described in the NRCS Soil Quality Test Kit. Five random subsamples were taken, composited, and transported to Siem Reap Town for air drying at room temperature. A total of 36 soil samples for laboratory tests were collected, passed through a 2-mm sieve, packed, and transported to the Coastal Plains Soil, Water and Plant Conservation Research Center, Agriculture Research Service, United States Department of Agriculture, Florence, South Carolina. USA.

2.3 Soil Organic Carbon and Total Nitrogen

Collected samples were analyzed for total organic carbon and total nitrogen through flash combustion method at high temperature using Vario MAX CNS Elemental Analyzer at Coastal Plains Soil, Water and Plant Research Center, Agricultural Research Service, USDA, Florence, SC. Percent soil organic carbon and total nitrogen were calculated based on bulk density of the soil.

2.4 Volumetric Water Content and Soil Temperature

Field testing of soil moisture and soil temperature was conducted on six farms; two farms per village, under CA and CT, respectively. The volumetric soil moisture content was measured from 10 subsampling points using a time domain reflectometer with 12 cm probe (TDR 100-Spectrum Tech) after calibration procedures. Soil moisture was measured after 18 to 24 hours following uniform irrigation. The soil temperatures were gathered using a field soil thermometer probe from 10 subsampling points and the temperature was checked using a second thermometer. Both TDR and temperatures were measured inside the vegetable beds about 15 cm to 30 cm away from the center of the plots' width, avoiding 1 meter from the plots borders. Percent water-filled pore space (%WFPS) were calculated based on volumetric water content and bulk density [19].

2.5 Soil Respiration

Soil respiration was measured 12 times, six from each of CA and CT, following the procedures published by Liebig and Doran [19]. Briefly, a 6-inch ring was driven into the soil, and after 1-2 hours it was covered with a rubber lid. After allowing carbon dioxide (CO_2) to accumulate for 30 minutes, the gas was sampled quantitatively by drawing 100-cm^3 suctions using a syringe attached via rubber tubing to a Draeger tube and a needle. A minor modification was done by purging the chamber five times before sampling and no needle was attached on the other side of the rubber lid. The purging and non-sticking of another needle were done to mix the gas trapped in the chamber and to avoid possible gases coming in from outside the chamber to be sampled, respectively. Soil respiration tests were conducted between 10:00am and 3:00pm. Actual field respiration was converted to kg CO_2-C ha^{-1} day^{-1} and normalized to 25ºC and 60% water-filled pore space (WFPS). Both actual and adjusted respiration rates were compared with a respiration index described in the USDA soil quality test kit [19, 24, 25].

2.6 Statistical analysis

The results for SOC and TN were analyzed using SAS PROC GLM [26]. Means of SOC, TN and other soil properties were separated at alpha=0.10 using Fisher's protected Least Significance Difference (LSD). Variation between farmer plots as blocks was also accounted for in the model. Dependent variables were pH, EC, bulk density, soil temperature, soil $\text{respiration}_{(\text{actual})}$, soil $\text{respiration}_{(@25°\text{C}\&\%60\text{WFPS})}$, volumetric water content, and water-filled pore space were also analyzed using SAS PROC GLM [26].

3. RESULTS AND DISCUSSION

3.1 Soil Organic Carbon

Differences in the total soil organic carbon (SOC) content for the three villages under CA and CT are presented in Table 3. Soil organic carbon varied significantly ($p \leq 0.001$) with tillage management for two villages (i.e., Srakat and Soutrnikum). The CA system in Srakat village (12.6±4.0 Mg ha^{-1}) and Soutrnikum village (13.3±2.7 Mg ha^{-1}) had greater concentration of SOC when compared with the amount of SOC in CT system of (10.4±2.0 Mg ha^{-1}) and (10.2±2.0 Mg ha^{-1}), respectively. In O' village, the SOC in CA (12.1±2.9 Mg ha^{-1}) was system was statistically comparable with the amount of SOC in CT system (13.4±5.1 Mg ha^{-1}). Averaged across soil depths, CA has greater concentration of SOC of about 2.2 Mg C ha^{-1} and 3.1 Mg C ha^{-1} than the amount of SOC in CT for Sratkat and Soutrnikum village, respectively (Table 3).

The increase of SOC in CA between the two villages may be due to the addition of about 15 Mg ha^{-1} rice mulch in two separate occasions before planting time. In addition, the planting of *Crotolaria juncea* in between rows of long-bean and cabbages during the second production prior to their harvesting time may also have added to the SOC of the soil. The root residues of previous crops, which were retained in CA and uprooted in CT, may have had added greater SOC in CA than in the system with CT. Our results were supported by the early findings of Stevenson [27] and Paustian et al. [28]. Al-Sheik et al. [29] showed that when a cover crop residue is incorporated or cover crop with deep root system is grown and incorporated in sandy soils, SOC sequestration can increase. When this happens, residues decay more rapidly for three main reasons: first, for the direct contact with soil-borne decomposing organisms; second, for the generally favorable soil conditions for microbial decomposition in terms of moisture and temperature; and third, for the favorable conditions for microbial activity resulting from optimum soil aeration [30].

For O' village, the lack of significant difference in SOC may be explained by having low organic matter input compared to other villages. Although we have added about the same amount of rice mulch to this village, tomato production for the second crop production was terminated as a result of high mortality of about 68% when averaged across all treatments. The soil was left bare for about six weeks while farmers were still deciding collectively what to plant. Also, cover crop production in this area was low because of high water table during the end of the rainy season and no watering at the beginning of the dry season. The effect of both cover crop and vegetable crop residues from the production of roots may have played an important role in increasing total soil organic carbon in Sratkat and Soutrnikum villages. It is generally recognized that the differential effects of crop rotations on SOC are simply related to the amount of above and belowground biomass produced and retained in the system. Retention of crop residues in our study is an essential component of CA for increasing or maintaining SOC. Factors that increase crop yields due to crop rotations will increase the amount of residue available and potentially soil carbon storage. The amount of crop residue retained after harvest, either on the soil or incorporated, is a key component to CA performance. The need to retain crop residues is important because of positive effect on increasing the amount of SOC as opposed to the traditional way of burning residues in the field.

Although substantial amount of work has been conducted on the individual influence of reduced tillage, residue retention, and crop rotation on soil organic carbon contents, results reported in the literature have mixed review. For instance, Govaerts et al. [31] inferred the potential for CA to increase soil organic carbon based on results from studies showing soil degradation when reduced tillage is practiced without ample residue cover in rain-fed or irrigated conditions in semi-arid or arid areas. Moreover, the findings of West and Post [32] has served as another basis when their analyses of 67 international studies revealed that experiments on wheat (*Triticum aestivum*) under no-till appeared to have greater SOC when wheat is rotated with one or more different crops (i.e., wheat-sunflower, *Helianthus annuus* or with wheat-legume) rotations in comparison to continuous wheat. In crop rotations involving winter vetch (*Vicia villosa*) planted as an additional legume in the cropping sequence SOC was significantly greater under zero tillage than under CT. In crop rotations involving winter vetch (*Vicia villosa*) planted as an additional legume in the cropping sequence SOC was significantly greater under zero tillage than under CT. However, the kind and number of rotation crops also matter. After 13 years of experimental data collection, West and Post [32] found no significant difference in SOC between zero tillage and CT under continuous wheat and soybean (*Glycine max*) sequence. Many of the differences of SOC accumulations may be due to soil type, topographic position, parent material and potentially their interactions and combination with management.

Additionally, the overall increase in SOC of CA when compared with CT in our study is seemingly associated with the following: i) keeping the disturbance impact between the mechanical implements and soil to an absolute minimum; ii) using effective crop rotations and association (Table 2); and iii) leaving crop residues as carbon source on the soil surface. The implementation of these practices is likely helpful in restoring a degraded agro-ecosystems to sustainable and productive state. Soil cover combined with reduced mechanical disturbance in CA system tends to make dryland (i.e., tropics and/or subtropics countries) soils more suitable for agriculture as compared to CT system. Further, the presence of mulch layers in CA can reduce soil temperature, resulting in high accumulation of SOC [33, 34].

3.2 Total Nitrogen

Table 4 shows the differences of soil total nitrogen as influenced by management at two depths among the three villages. The average total nitrogen in soils under CA and CT did not differ significantly in O' village and Sratkat village (Table 4). In O' village, the verage SOC in CA was about 0.79±0.17 Mg ha^{-1} and 0.90±0.28 Mg ha^{-1} in CT. The average amount of SOC in Sratkat village with CA was about 0.94±0.18 Mg ha^{-1} compared with 0.90±0.15 Mg ha^{-1} in CT. Concentration of total nitrogen does not vary with soil depths among the three villages. However, at Soutrnikum village under CA, the total nitrogen was observed to be 240 kg ha^{-1} higher than the average amount of total nitrogen in CT. The reason might be due to the addition of *Crotolaria juncea* in the soil under CA. Mansoer et al. [35] reported an increase of 57 kg of nitrogen after nine to 12 weeks of growing this cover crop (*Crotolaria juncea*) while Rotar and Joy [36] reported an increase of about 60 kg N after 60 days production due to *Crotolaria juncea* in CA.

For Sratkat village having added with *Crotolaria juncea*, the trend shows that there was an increase in total nitrogen in both soil layers of 0-10 cm and 10-20 cm, albeit not significantly greater than CT. In contrast, O' village, as described earlier, was planted with cover crop but with poor growth, because it was no longer irrigated having no commercial crop involved at the onset of the dry season which may have had affected the total soil nitrogen content (Table 4).

The increased amounts of total nitrogen under CA in Trabek District (Soutrnikum village) can be related to the residue on the soil surface, which generate a better environment for microbial activity and organic matter mineralization [37, 38]. Cover crop has likewise showed favorable effects by conserving and increasing the concentration of nitrogen in the soil. Cover crops which are commonly present in system with CA conserve nitrogen by converting mobile nitrate-N into immobile plant protein by providing timely competition to other nitrogen loss process, such as leaching or denitrification. Delgado [39] conducted cover crop studies with irrigated vegetable and small grain systems and found a positive correlation among root depth, N use efficiency and nitrate uptake from shallow groundwater. The deeper rooted cover crops functioned like vertical filter strips to scavenge nitrates from soil and recover nitrates from underground water.

3.3 Soil pH and Soil Electrical Conductivity

Soil pH and soil electrical conductivity did not vary significantly with management treatments. The soils of the study site have pH ranges from strongly acidic to moderately acidic while soil electrical conductivity varies from non-saline to slightly saline (Table 5). The soil volumetric water content and percent water-filled pore space were significantly higher in CA (20.0±11.9 % and 41.4±23.3%) compared with CT (15.7±8.6% and 33.2±19.0%), which may be due to the mulch that acted as barriers from solar radiation, wind, and the impact of water from irrigation that may seal the soil pores due to crust formation, if uncovered, during the dry season. It is expected the H^+ ions will move down throughout the soil profile, but the slow infiltration rate due the presence of mulch acting as barrier especially in CA and under NT increases the probability of maintaining the released H+ ions near the soil surface [40].

The electrical conductivity of the soil was less than 1 dS m^{-1} in both CA and CT systems (Table 5), which is indicative of no salinity problems. Under the CT (0.6±1.1 dS m^{-1}), the electrical conductivity was higher as compared to CA (0.6±1.1 dS m^{-1}), but the difference was not statistically different. The lower EC observed in CA can be associated to greater biological activity in this system. Biological processes such as nitrification increases the transformation of

SOC and the potential liberation of H^+ ions that can cause a decrease in the electrical conductivity.

3.4 Soil Respiration and Soil Temperature

The actual soil respiration rate (Table 6) for CA of 55.9 ±4.8 CO_2-C per ha^{-1} day^{-1} was greater by 19.7 CO_2-C per ha^{-1} day^{-1} than the average soil respiration in CT (36.2±13.5 CO_2-C per ha^{-1} day^{-1}). The CO_2 produced from the soil and released to the soil surface may come from several sources with about half derived from metabolic activity to support the growth of roots and mycorrhizae, and the remaining are associated with heterotrophic respiration from microbial communities while a small portion comes from decomposition of carbon compounds as noted by Ryan and Law [41], who reviewed work from several authors.

Soil respiration is an indicator of soil microbial activity and organic matter decomposition in the soil, although higher soil microbial activity may not necessarily be beneficial all the time [24]. With this, CA may have had higher soil organic matter decomposition from the added residues in the soil or from the microbial activity or both. With higher soil carbon mineralization in this case, nutrients will be released for use by plants or by the organisms living in the soil.

When the values of soil respiration were compared to the index provided for by Soil Quality Institute Staff [24], CA shows to fall in the middle of the index range stating that it has an “ideal soil activity” with an added explanation that that the “soil is at an ideal state of biological activity and has adequate soil organic matter and active populations of microorganisms.” In comparison, CT falls along the border between “ideal soil activity” and “medium soil activity” where medium soil activity was described as “the soil is approaching or declining from an ideal state of biological activity.”

The value obtained from our study with CA was at the middle range of ideal soil activity. It was described as the soil was at an ideal state of biological activity with sufficient organic matter and active populations of microorganisms, while the conventionally tilled are in the middle between medium soil activity and ideal soil activity wherein the soil was approaching or declining from an ideal state of biological activity [24].

Soil respiration is an indicator of soil microbial activity. It is measured through respired CO_2 and is thus a measure of the capacity of the soil to degrade organic matter. Tillage systems affect CO_2 release. Ussiri and Lal 18] observed lower CO_2 released from soils under zero tillage in comparison to those under conventional tillage with continuous corn. Similarly, for soils grown with corn, Almaraz et al. [42] reported lower CO_2 respired from top soils under zero tillage in comparison to CT, regardless of whether there were residues retained or not in both systems. Lower respired CO_2 was attributed to the protection of soil organic carbon by the stable soil aggregates under no-till, leading to slower decomposition rates of SOC under such system [42]. However, when no-till was combined with permanent residue cover under corn-wheat rotation, Oorts et al. [43] found no significant difference or even greater released of CO_2 from no-till than from conventionally tilled soils without residue cover. While the findings of Oorts et al. [43] is specific to their climatic and soil conditions, it is unclear whether similar results would be seen under CA's more diversified crop rotations under other types of climate, soil, and organic residue covers. Again, many of the differences may be due to different soil types, topographic position, parent material and their combination and interaction with management.

Soil temperature plays an important role in seed germination, activity of soil microbes, and evapotranspiration. Temperature of soils under CA (30.4°C±2.0) was lower by 2.0°C than CT (32.4°C ±2.3) soils (Table 6). This was because the soils under CA were covered with mulch from rice straws at about 8 cm thick while the conventionally tilled soils were left bare. Soils in CA or no-till systems are often cooler and wetter than under conventional plowing regimes [8, 44].

4. SUMMARY AND CONCLUSIONS

Soil organic carbon ($p \leq 0.01$), soil total nitrogen ($p \leq 0.01$) and soil respiration ($p \leq 0.10$) for at least in two villages in Siem Reap, Cambodia were significantly affected by tillage management. After two harvests, addition of residues from mulch, and cover crop production, the average soil organic carbon was observed to be higher in CA compared with CT. The overall increase in SOC of CA when compared with CT in our study is seemingly associated with the following: a) keeping the disturbance impact between the mechanical implements and soil to an absolute minimum; b) using effective crop rotations and association; and c) leaving crop residues as carbon source on the soil surface. The legume cover crop *Crotolaria juncea* may have increased soil organic carbon and total nitrogen. Field soil respiration rate, based on actual field soil temperature and moisture indicate a good micro-climate for the growth and proliferation of soil fauna, as well as the release of nutrients from the mineralization of soil organic carbon. Also, lower soil temperature and higher soil water content were observed during the dry season in CA compared with CT. The soil's function of supporting plant growth, habitat for soil microorganisms, and sink for carbon and recycler of nutrients likely improved in CA than in CT. Our results have suggested that CA may have had improved soils' carbon and nitrogen contents, nutrient supplying capacity and microclimate for soil microorganisms. Moreover, results of our study supported the overall concept and/or premise of CA. Conservation agriculture is a concept of crop production that aims to save resources, strives to achieve acceptable profits with high and sustained production levels, while at the same time conserving the environment.

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LIST OF FIGURES:

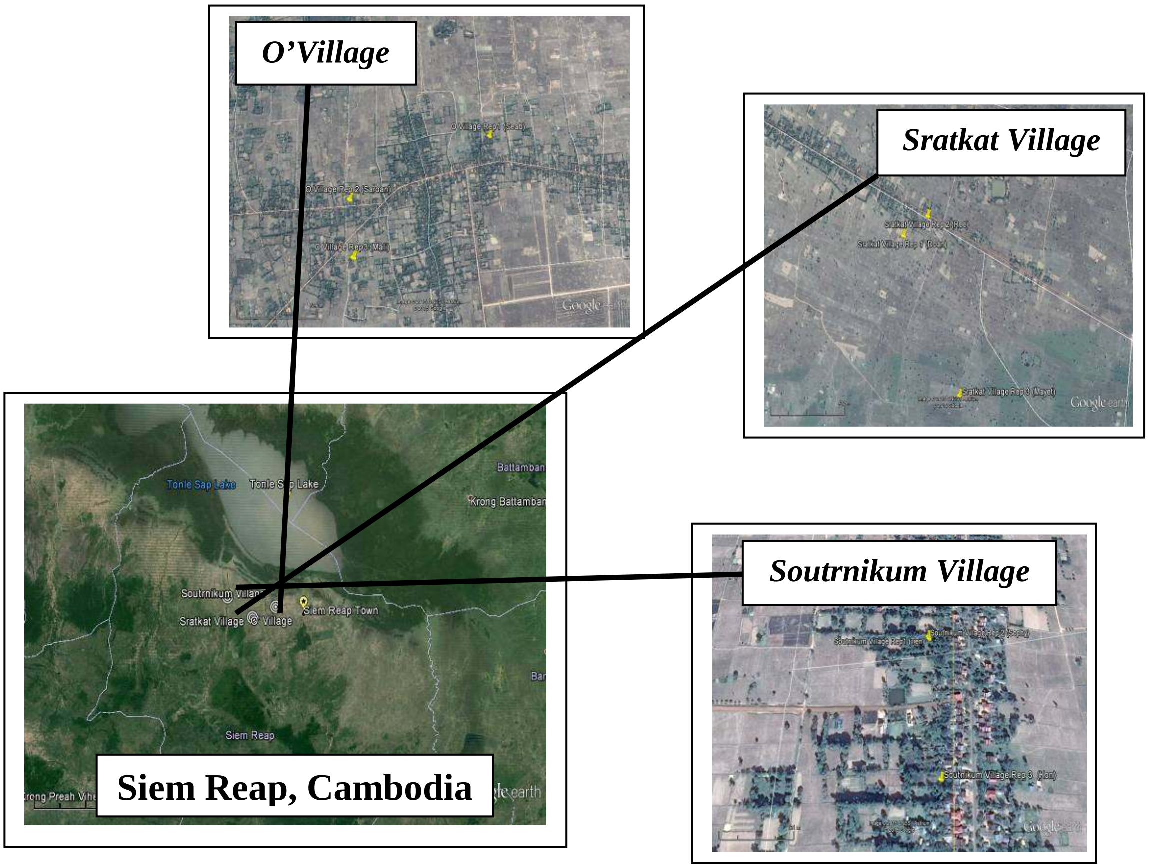
O’Village
Sratkat Village
Soutrnikum Village
Siem Reap, Cambodia
Tonle Sap Lake
Siem Reap Town
Siem Reap

Figure 1.

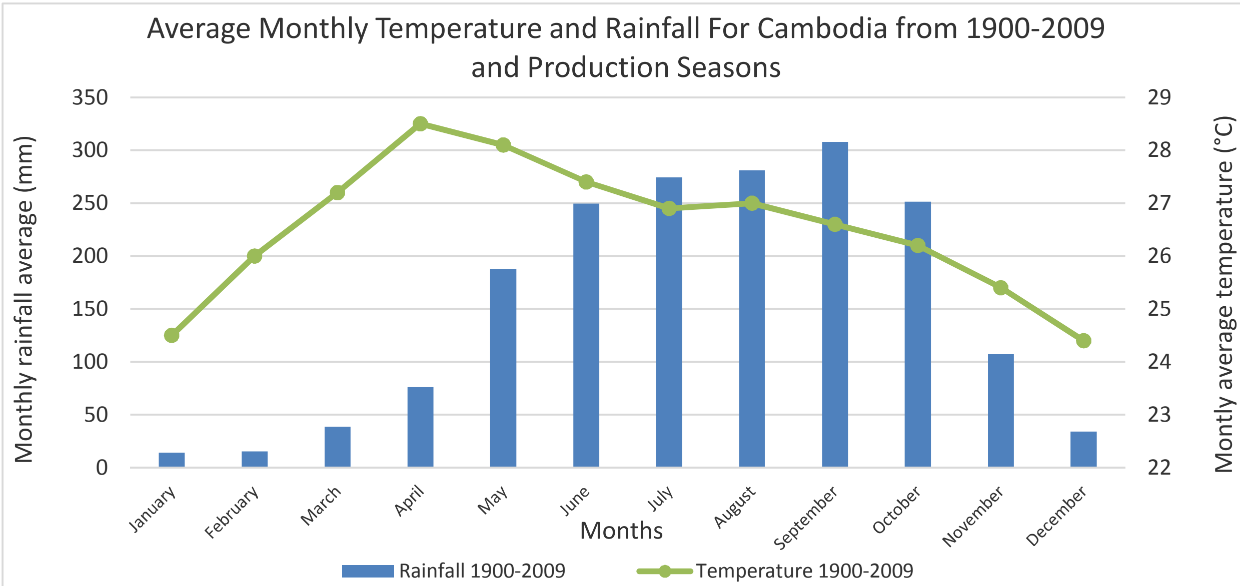
Average Monthly Temperature and Rainfall For Cambodia from 1900-2009
and Production Seasons
Monthly rainfall average (mm)
Montly average temperature (°C)
350
300
250
200
150
100
50
0
29
28
27
26
25
24
23
22
January
February
March
April
May
June
July
August
September
October
November
December
Months
Rainfall 1900-2009
Temperature 1900-2009

Figure 2.

Figure 3.

Table 1. Selected properties of soils in the study sites located in Siem Reap, Cambodia.

Soil Properties	**n**	***O' village***	***Sratkat Village***	***Soutrikum Village***
		Villages		
pH	36	5.15±0.45	6.10±0.97	6.31±0.64
EC (uS cm^{-1})	36	80.0±30.0	211.0±120.0	306.0±136.0
Soil Organic Carbon (g kg^{-1})	36	8.8±2.5	7.9±2.1	8.3±2.2
Total Nitrogen (g kg^{-1})	36	0.58±0.15	0.64±0.11	0.70±0.14
Potassium (mg kg^{-1})	36	72.4±43.2	83.7±43.2	125.2±41.1
Phosphorus (mg kg^{-1})	36	69.7±21.5	69.7±43.6	76.4±30.7
Bulk Density (g cm^{-3})	36	1.44±0.11	1.45±0.10	1.42±0.07

Table 2. Management and rotation of crops in three villages, Siem Reap, Cambodia.

Planting Season	**Crop selection by Village**
	---------- **O'Village, Prasat Bakong District** -------
Early wet season 2013	Cucumber (*Cucumis sativus* L).
Wet to dry season 2013	Tomato (*Solanum lycopersicum* L).
Dry Season 2013 -2014	Yard-long bean (*Vigna unguiculata* L. subsp. *Sesquipedalis)*
Early Wet season 2014	Round eggplant (*Solanum melongena* L.)
	---------- **Sratkat Village Prasat Bakong District** -------
Early wet season 2013	Cucumber (*Cucumis sativus* L).
Dry season 2013	Yard-long bean (*Vigna unguiculata* L. subsp. *Sesquipedalis)*
Dry season 2014	Cauliflower (*Brassica oleracea* L.var. *botrytis)*
Early wet season 2014	Eggplant (*Solanum melongena* L)
	---------- **Soutrnikum Village Trabek District** -------
Wet season 2013	Chinese kale (*Brassica oleracea* L. var. *Aboglabra)*
Wet to dry season 2013	Cabbage (*Brassica oleracea* L. var. *Capitata)*
Early wet to wet season 2014	Tomato (*Solanum lycopersicum* L*)*
Wet season 2014	Yard-long bean (*Vigna unguiculata* L.subsp. *sesquipedalis)*

Table 3. Comparison of soil organic carbon in conservation agriculture and conventional tillage among three villages in Siem Reap, Cambodia.

Production Management	------------------O' village-------------			---------------Sratkat Village-----------			------------Soutrnikum Village---------		
	---------Depth---------			---------Depth---------			---------Depth---------		
	0-10 cm	10-20 cm	Mean	0-10 cm	10-20 cm	Mean	0-10 cm	10-20 cm	Mean
	-------------------Soil Organic Carbon (Mg ha^{-1}) -------------------								
CA	10.5±1.3	13.6±3.4	12.1±2.9	13.3±5.3	11.9±3.2	12.6±4.0^{a}	14.2±2.7	12.5±3.0	13.3±2.7^{a}
CT	14.3±6.1	12.6±4.9	13.4±5.1	10.2±2.1	10.5±2.3	10.4±2.0^{b}	11.4±2.1	6.0±1.2	10.2±2.0^{b}
Mean	12.4±4.4	13.1±3.8		11.7±4.0	11.2±2.6		12.8±2.6	10.7±2.8	
LSD$_{0.10}$						2.1			2.2
n	12	12		12	12		12	12	
Sources of Variation	**F-value**	***P***		**F-value**	***P***		**F-value**	***P***	
Block	8.74	<0.01**		10.63	0.01**		2.61	0.15^{ns}	
Management (M)	0.88	0.38^{ns}		4.12	0.08**		7.11	0.04**	
Depth (D)	0.27	0.62^{ns}		0.25	0.63^{ns}		3.14	0.13^{ns}	
M*D	2.61	0.16^{ns}		0.54	0.49^{ns}		0.11	0.76^{ns}	

$^{***}p \leq 0.01$; $^{**}p \leq 0.05$; $^{*}p \leq 0.10$; ^{ns}Not significant; CA=Conservation agriculture; CT=Conventional tillage
Means under each column with different letters are significantly different

26

Table 4. Comparison of soil total nitrogen in conservation agriculture and conventional tillage among three villages in Siem Reap, Cambodia.

	------------------O' village-----------------			-----------------Sratkat village---------			------------Soutrnikum village----------		
	---------Depth---------			---------Depth---------			---------Depth---------		
Production Management	0-10 cm	10-20 cm	Mean	0-10 cm	10-20 cm	Mean	0-10 cm	10-20 cm	Mean
	------Total Nitrogen (Mg ha^{-1}) ------								
CA	0.74±0.12	0.85±0.22	0.79±0.17	0.96±0.25	0.92±0.13	0.94±0.18	1.15±0.16	1.07±0.14	1.11±0.14^{a}
CT	0.93±0.32	0.87±0.30	0.90±0.28	0.92±0.16	0.87±0.18	0.90±0.15	0.96±0.09	0.79±0.08	0.87±0.12^{b}
Mean	0.83±0.23	0.86±0.24		0.94±0.19	0.90±0.14		1.05±0.16	0.93±0.18	
$LSD_{0.10}$									0.12
n	12	12		12	12		12	12	
Sources of Variation	***F*-value**	***P***		***F*-value**	***P***		***F*-value**	***P***	
Block	11.84^{ns}	<0.00***		8.73^{ns}	<0.01**		1.91	0.22^{ns}	
Management (M)	1.33^{ns}	0.29^{ns}		0.46^{ns}	0.52^{ns}		13.47	0.01**	
Depth (D)	0.56^{ns}	0.48^{ns}		0.46^{ns}	0.52^{ns}		3.46	0.11^{ns}	
M*D	1.03^{ns}	0.34^{ns}		0.02^{ns}	0.88^{ns}		0.43	0.53^{ns}	

$^{***}p \leq 0.01$; $^{**}p \leq 0.05$; $^{*}p \leq 0.10$; ^{ns}Not significant; CA=Conservation agriculture; CT=Conventional tillage
Means under each column with different letters are significantly different.

27

Table 5. Effect of CA and CT on soil pH, electrical conductivity, volumetric water content and water filled pore space.

	------------------------------------Field Measured Soil Quality Parameters------------------------------------			
Production Management	pH	EC dS m^{-1}	Volumetric water content (%)	Water filled pore space (%)
CA	5.1±0.9	0.2±1.8	20.0 ± 11.9^{a}	41.4 ± 23.3^{a}
CT	5.1±0.8	0.6±1.1	15.7 ± 8.6^{b}	33.2 ± 19.0^{b}
$LSD_{(0.10)}$			3.9	7.9
n	34	34	12	12
Sources of Variation	***F*-value**	***F*-value**	***F*-value**	***F*-value**
Block	20.6^{***}	2.3^{ns}	18.1^{***}	18.4^{***}
Management	0.4^{ns}	1.97^{ns}	5.0^{*}	4.4^{*}

$^{***}p \leq 0.01$; $^{**}p \leq 0.05$; $^{*}p \leq 0.10$; ^{ns}Not significant; CA=Conservation agriculture; CT=Conventional tillage
Means with different letters under each column are significantly different

Table 6. Soil temperature and average soil respiration as affected by CA and CT.

Production Management	Temperature (°C)	Actual Soil Respiration (kg CO_2-C per ha^{-1} day^{-1})	Soil Respiration (adjusted to 25°C and 60% WFPS)
	--------------------------------Field Measured Soil Quality Parameters-----------------------------		
CA	30.4 ± 2.0^{a}	55.9 ± 4.8^{a}	84.1 ± 40.8
CT	32.4 ± 2.3^{b}	36.2 ± 13.5^{b}	59.9 ± 51.3
$LSD_{(0.10)}$	1.1	11.03	
n	12	12	12
Sources of Variation	***F*-value**	***F*-value**	***F*-value**
Block	9.4^{**}	1.29^{ns}	6.8^{*}
Management	12.7^{**}	13.0^{*}	3.2^{ns}

$^{***}p \leq 0.01$; $^{**}p \leq 0.05$; $^{*}p \leq 0.10$; ^{ns}Not significant; CA=Conservation agriculture; CT=Conventional tillage
Means with different letters under each column are significantly different

29