Carbon Sequestration in Organic and Conventional Corn Production System

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Full Paper

Carbon Sequestration in Organic and Conventional Corn Production System

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Global warming brought about by increasing concentration of green house gases (GHG) in the atmosphere, particularly that of CO_2, is a major concern due to its impact on climate change. The intensity and frequency of typhoons, drought and flooding increased due to the change in climate and these have a negative impact on crop productivity and food security. Alternative farming practices that can potentially reduce CO_2 emission and optimize the efficiency of plant and soil carbon sequestration is therefore necessary. Thus, this experiment was conducted to determine and compare the potential contribution of organic and conventional corn production systems on carbon sequestration based on plant biomass and soil organic carbon accumulation. The field experiment was conducted at the Central Experiment Station, Pili Drive, UP Los Baños, College Laguna from June to September 2012 for the wet season experiment, and from February to May 2013 for the dry season experiment. Four fertilizer treatments and two corn cultivars served as mainplot and subplot, respectively, and were laid out in split-plot in RCBD with three replications. The cultivars evaluated were USM Var 10, a high yielding open-pollinated variety and Crystal, a farmer-selected open-pollinated cultivar. Fertilizer treatments were control, inorganic fertilizer (138 kg N from urea), and organic fertilizer in the form of vermicompost. The rate of vermicompost used during the wet season was 8 t ha^{-1} while during the dry season 8 and 10 t ha^{-1} was used. Data on root and shoot biomass and organic carbon content, soil organic carbon, and bulk density were monitored at 30 and 60 days after sowing during the wet season and until 90 days after sowing during the dry season. Plant carbon (C) sequestration was calculated based on root and shoot biomass and on the carbon content of the plant tissues. Soil C sequestration was calculated based on soil organic carbon content, soil depth and bulk density. For both wet and dry season experiments, the use of inorganic fertilizer contributed to highest total plant C sequestration. Between the two cultivars, USM Var 10, a high yielding open-pollinated variety, contributed more to C sequestration. Soil C sequestration was likewise highest using inorganic fertilizer, but values did not differ during the wet and dry season. The total carbon sequestration using inorganic fertilizer was undeniably much greater than using vermicompost. However, considering the adverse environmental impacts of inorganic fertilizer, (i.e. CO2 emission during its manufacture, transport, and use; deterioration of soil and water quality; and impact on human) this may reduce its C sequestration potential.

Keywords: carbon sequestration, climate change, corn, conventional corn production, organic corn production, plant carbon sequestration, soil carbon sequestration

INTRODUCTION

Global warming brought about by increasing concentration of green house gases (GHG) in the atmosphere is a major concern due to its impact on climate change. Among the GHGs, carbon dioxide accounts for 72% of the total GHG emission making it the most important cause of global warming. From the current concentration of 387 ppm, it is increasing at the rate of 1.5 ppm a^{-1} (Wang et al. 2010), which led to a substantial increase in global surface temperature and altered the distribution of precipitation and increased the frequency of natural disasters (Lal 2007).

The atmospheric concentration of CO_2 and other GHG such as nitrous oxide (N_2O) and methane (CH4) increased drastically since the industrial revolution (Wang et al. 2010). Agriculture is reported to release significant amounts of CO_2, CH_4 and N_2O to the atmosphere (Cole et al. 1997). On a global scale, a GHG emission from agricultural land use is estimated at 10-12% or 5.1-6.1 Gt of the total anthropogenic annual emissions of CO_2-equivalents (IPCC 2007). CO_2 released from agriculture comes largely from microbial decay and burning of plant residues (Janzen 2004). The current farming practices that are highly dependent on external chemical inputs, such as fertilizers and pesticides, also contribute to increased carbon emissions through their manufacture. The production of mineral fertilizers contributes 1% to the global anthropogenic (man-made) GHG emission (Williams 2006). The use of these chemical inputs also depletes soil organic matter thereby releasing CO_2 into the atmosphere (Pretty and Ball 2001).

The challenge therefore, is adopting farming practices that can help reduce GHG emission in the atmosphere, optimize the efficiency of carbon sequestration, and maintain the same level of crop productivity. Organic farming is increasingly being recognized as having the greatest potential to address all these issues. Recent studies reported on the contribution of organic agriculture in increasing carbon sequestration and reducing CO_2 emission and in maintaining or increasing yield. Organic rice fields in Indonesia showed a 30% higher soil carbon storage (25.0 Mg ha^{-1}) over that of conventional field (17.6 Mg ha^{-1}) (Komatsuzaki and Syuaib 2010). In soybean, an increased total organic carbon was observed with the application of organic amendments compared to inorganic fertilizer (Gilani and Bahmanyar 2008). Enhanced soil organic carbon pool was also observed with the use of organic manures and compost more than the application of the same amount of inorganic fertilizer (Gregorich et al. 2001). In the Rodale Farming Systems Trial in the mid-Atlantic region of the continental USA, manure-based organic system sequestered 1218 kg C ha^{-1} a^{-1} while legume-based organic system sequestered 857 kg, and the conventional system sequestered 217 kg (Pimentel et al. 2005). It was estimated that the global average sequestration potential of organic croplands is between 0.9-2.4 Gt CO_2 a^{-1} (Niggli et al. 2009). This is equivalent to an average sequestration potential of about 200-400 kg C ha^{-1} a^{-1} for all croplands.

To meet the increasing demand for corn, both for food and for industrial use, the volume and area of production will also increase as more farmers engage or shift to corn farming. Increasing the volume and area of corn production could potentially increase CO_2 sequestration thru biomass production and conversion of sequestered carbon into more stable soil organic matter. During photosynthesis, carbon from atmospheric CO_2 is transformed into components necessary for plants to live and grow. Once the plant dies, it decomposes and some of the carbon is released into the atmosphere but some are captured within the soil and increases the soil organic matter (TEEIC 2012).

However, corn production relies mainly on inorganic fertilizer and chemical pest control to increase yield and food supply, practices that contribute to green house gas emission. Information on carbon sequestration in organic corn production under Philippine condition is very limited which makes it more difficult to promote and convince farmers to shift to organic farming as a way to mitigate and adapt to climate change. Thus, this experiment aimed to determine the carbon sequestration capacity of high yielding and farmer-grown open pollinated corn cultivars and to compare the potential contribution of organic and conventional corn production systems on CO_2 sequestration based on plant biomass production and soil organic carbon accumulation. During the experiment, plants were inadvertently subjected to abnormal growing conditions either due to excessive or insufficient rainfall. The occurrence of successive typhoons and monsoon rains during the months of July-October 2012 caused flooding and waterlogged condition in the experimental area which coincided with the vegetative stage of the plants. On the other hand, plants were subjected to drought during the months of February-May 2013 because of very little rain and relatively higher temperature during this period. Due to the prolonged waterlog and drought conditions biomass production and consequently carbon sequestration was severely affected.

MATERIALS AND METHODS

Time and Place of the Study

The field experiment was conducted at the Central Experiment Station (CES), Pili Drive, UP Los Baños (UPLB), College Laguna, Philippines, from June to September 2012 for the wet season experiment, and from February to May 2013 for the dry season experiment. The laboratory analysis for total carbon content of plant tissues was done at the Analytical Services Laboratory of the Institute of Plant Breeding, College of Agriculture and Food Science (CAFS), UPLB. The soil organic carbon content was analyzed at the Soil Testing Laboratory, Agricultural Systems Institute, CAFS, UPLB.

Experimental Design, Treatment and Crop Establishment

The experimental factors were two corn varieties and three fertilizer treatments. The corn varieties included a white local farmer-grown variety ‘Crystal’, obtained from Cagayan Valley, and USM Var 10, a high yielding open pollinated variety. The fertilizer treatments were the following: control (zero fertilizer), vermicompost, and inorganic fertilizer. During the wet season experiment, the vermicompost treatment was only 8 t ha^{-1}. But during the dry season, 8 and 10 t ha^{-1} of vermicompost rates were evaluated. The factors were arranged in split-plot in RCBD with 3 replications. Fertilizer treatment served as mainplot and corn cultivar as subplot. Each subplot had an area of 30 m^2. Each block was separated by a 1.5 m alley, while mainplots were spaced 1 m apart.

The recommended rate of inorganic fertilizer, based on the results of the soil analysis, was 6 bags of Urea ha^{-1}, equivalent to 135 kg of nitrogen (N). Results of the soil analysis showed sufficient amount of phosphorous (P) and potassium (K) such that the fertilizer recommendation was only for N (135-0-0 kg NPK ha^{-1}). The vermicompost used contains 1.66% N, so the amount of N applied for the 8 t ha^{-1} rate was equivalent to the recommended rate for inorganic fertilizer while that of 10 t ha^{-1} was equivalent to 166 kg of N. All of the recommended amount of vermicompost was applied at planting. For the inorganic fertilizer (Urea), half of the recommendation was applied basally and the other half applied as side dress at 25 d after sowing (DAS). The vermicompost was applied along the furrows, before the seeds are sown. The inorganic fertilizer were also applied along the furrows but was first covered with a thin layer of soil before seeds were sown. This was done to avoid direct contact between the fertilizer and the seeds thereby preventing possible damage on the seeds.

Corn seeds were sown at a distance of 20 cm between hills and 0.75 m between rows at 3 seeds per hill. The experimental plots were irrigated the day after sowing to moisten the soil and initiate seed germination. Seedlings were thinned to two per hill 2 wk after germination. Missing hills were replanted 1 wk after germination.

Insect pests in the conventional plots were managed following the recommended crop protection practices while that of the organic plots were managed using alternative crop protection practices. Pest control was done when the need arises. Weed management in both conventional and organic plots was done manually and only when the need arises.

During the dry season experiment, furrow irrigation was done almost every wk after seedling emergence until at least a wk before harvesting. However, there were times that irrigation was delayed due to inadequate water supply or unavailability of irrigation pipes.

Data gathered

The shoot and root biomass were monitored starting at 30 d after sowing (DAS) and every 15 d thereafter, while bulk density and soil organic carbon were monitored at 30, 60 and 90 DAS. However, during the wet season, the shoot and root biomass were monitored up to 60 DAS only since plants did not survive the waterlogged condition beyond 60 DAS.

Shoot and root biomass

Five randomly selected plants from each treatment plots were carefully dug to collect as much of the roots as possible. The roots and shoots of individual plant samples were then separated and oven-dried at 70 °C for 72 h or until a constant dry weight was attained. Samples that were very wet were air-dried first before oven drying. When constant dry weight was attained, the root and shoot samples were weighed separately. The dried tissues were analyzed for percent organic carbon content of the roots and the shoots. The root and shoot biomass per ha were computed and was used as the basis for determining the above and below ground carbon sequestration.

Carbon sequestration potential

Above and below ground carbon sequestration potential of corn was determined by separately analyzing the carbon content of shoot and root tissues. Soil carbon sequestration was determined from soil samples taken from each of the treatment plots.

***Plant carbon sequestration* (Mg ha^{-1})**. A 10-g composite sample of dried shoots and roots from each of the treatment combination was brought to the Analytical Services Laboratory of the Institute of Plant Breeding, UPLB, for the analysis of total carbon content. The total carbon sequestered was calculated using the formula:

$$\text{CS Plant} = [(\text{SDM})(\text{SCC})] + [(\text{RDM})(\text{RCC})]$$

Where:
CSPlant= Plant Carbon Sequestration
SDM= Shoot dry matter, t ha^{-1}
SCC= Shoot carbon content, (amount in percent/100)
RDM = Root dry matter, t ha^{-1}
RCC = Root carbon content, (amount in percent/100)

***Soil organic carbon sequestration* (Mg ha^{-1}).** Soil samples within the 0-25 cm depth were collected from each plot using an auger and analyzed for organic carbon content following the Walkley-Black Procedure. Bulk density was also determined by taking soil samples from each of the plot using a core sampler. Soil plus the core sampler weight was recorded before drying the samples overnight at 105 C. Soil plus core sample weight was recorded after oven drying for the calculation of bulk density. Soil organic carbon storage was calculated based on the formula of Komatsuzaki and Syuaib (2010):

$$\text{SCS} = \text{BD} \times \text{SOC} \times \text{DP}$$

where:
SCS = Soil organic carbon storage (Mg ha^{-1})
BD = Bulk density (g cm^{-3})
SOC = Soil organic carbon content (%)
DP = Soil depth (cm)

RESULTS AND DISCUSSION

Wet Season Experiment

Plant Carbon Sequestration

Root, shoot and total plant carbon sequestrations at 30 and 60 DAS were significantly highest in plants grown under inorganic fertilizer treatment. USM Var 10 also consistently showed significantly higher shoot and total plant carbon sequestration than Crystal (Table 1). The greater carbon sequestration of plants grown with inorganic fertilizer can be attributed to better crop growth and higher biomass production (Table 2). Due to the bigger leaf area of plants grown with inorganic fertilizer, photosynthetic rate was higher resulting to greater net assimilation rate and consequently greater biomass production. At 30 DAS, despite the greater shoot biomass compared to the root biomass, the amount of carbon sequestered in the roots is almost the same as the amount sequestered in the shoots. This is attributed to the higher organic carbon content in the roots than in the shoots (Table 3). This response is typical in most cereal grains where carbon allocation to the roots is highest during the early growth stages and declines at flowering (Crawford et al. 2000; Hulugalle et al. 2009). Later, when the roots are fully established, most of the carbon is then allocated to the shoots for the grain yield, hence, at 60 DAS carbon sequestration in the shoot increased tremendously.

The amount of carbon sequestered by the plants regardless of the fertilizer treatment were quite low compared to the amount reported in the literatures ranging 200-1200 kg C a^{-1} (Pimentel et al. 2005). The

Table 1. Root, shoot and total plant carbon sequestration of USM Var 10 (high-yielding variety) and Crystal (farmer-selected cultivar) at 30 and 60 days after sowing (DAS), 2012 wet season, Los Baños, Laguna, Philippines

	Plant carbon sequestration (Mg ha^{-1})					
	30 DAS			60 DAS		
	Root	Shoot	Total	Root	Shoot	Total
Fertilizer treatment						
Control	0.001 b	0.002 b	0.003 b	0.003 b	0.016 b	0.020 b
Inorganic	0.009 a	0.012 a	0.020 a	0.047 a	0.091 a	0.138 a
Vermi (8 t ha^{-1})	0.001 b	0.002 b	0.003 b	0.003 b	0.007 b	0.010 b
Variety						
USM Var 10	0.004 a	0.005 a	0.009 a	0.022 a	0.048 a	0.070 a
Crystal	0.004 a	0.005 a	0.008 a	0.013 a	0.028 b	0.042 b

Means followed by the same letter within columns are not significantly different using LSD at 5% level

Table 2. Total dry matter of USM Var 10 (high-yielding variety) and Crystal (farmer-selected cultivar) at 30 and 60 days after sowing (DAS), 2012 wet season, Los Baños, Laguna, Philippines

	Total dry matter (kg ha^{-1})	
	30 DAS	60 DAS
Fertilizer treatment		
Control	49.56 b	410.34 b
Inorganic	399.28 a	3796.76 a
Vermi (8 t ha^{-1})	63.00 b	261.73 b
Variety		
USM Var 10	173.46 a	1663.96 a
Crystal	167.76 a	1315.26 b

Means followed by the same letter within columns are not significantly different using LSD at 5% level

Table 3. Root and shoot organic carbon content of USM Var 10 (high-yielding variety) and Crystal (farmer-selected cultivar) at 30 and 60 days after sowing (DAS), 2012 wet season, Los Baños, Laguna Philippines

	Organic carbon content (%)			
	30 DAS		60 DAS	
	Root carbon	Shoot carbon	Root carbon	Shoot carbon
Fertilizer treatment				
Control	8.04 a	3.99 b	6.67 b	4.38 a
Inorganic	7.52 b	4.10 a	6.97 a	2.90 b
Vermi (8 t ha^{-1})	7.44 b	4.59 a	6.30 c	3.06 b
Variety				
USM Var 10	7.93 a	4.53 a	6.52 b	3.92 a
Crystal	7.39 b	3.93 b	6.78 a	2.97 b

Means followed by the same letter within columns are not significantly different using LSD at 5% level

wet season experiment was characterized by excessive rainfall due to the occurrence of typhoons and monsoon rains. The continuous downpour and high volume of rainfall saturated the soil in the experimental area until it became flooded and waterlogged. This growing condition resulted to poor plant growth and therefore low dry matter production and consequently low plant carbon sequestration.

Among the fertilizer treatments, plant growth was best under inorganic fertilizer resulting to the highest amount of plant carbon sequestered. The enhanced plant growth under inorganic fertilizer treatment implies that both cultivars are more adapted to this kind of fertilizer. This response could be the result of years of cultivation under conventional production system. The potential carbon sequestration of the corn cultivars, therefore, depends to a greater extent on improved plant growth. Since inorganic fertilizer improved plant growth better than vermicompost, plant carbon sequestration in this fertilizer treatment was highest. However, the manufacture of inorganic fertilizer alone contributes to CO_2 emission (Williams 2006). For urea, producing 1 kg of the product releases 0.91 kg CO_2-eq (Bentrup and Pallière 2014). Thus, carbon sequestered through improved plant growth may be reduced by the CO_2 emitted not only during its manufacture but also during its transport. On the other hand, CO_2 emissions from vermicompost can not be quantified. According to Sánchez et al. (2015) the CO_2 emissions from composting facilities are considered biogenic CO_2 emissions so the global warming potential of these emissions are not taken into account because they are considered carbon neutral.

Soil Organic Carbon Sequestration

Inorganic fertilizer showed the highest SOC sequestration 30 and 60 DAS (Table 4). This is contrary to the report that soil carbon sequestration is higher with organic fertilizer application than inorganic amendment (Komatsuzaki and Syuaib 2010; Gregorich et al. 2001). The higher SOC in inorganic fertilizer may be attributed to better plant growth, resulting to higher root biomass production and enhanced SOC (Follet 2001).

Carbon sequestration for all fertilizer treatments declined at 60 DAS (Table 4). During this time, photosynthesis was already severely affected due to waterlogging. This caused a decrease in root biomass production and a decrease in carbon input from the roots, hence the decline in SOC. Another possible reason for this occurrence is that dissolved organic carbon may have been carried into the deeper soil horizon by water moving downwards (Steinbeiss et al. 2007). The transport of dissolved organic carbon into the deeper soil horizon may also explain the low SOC of vermicompost.

The bulk density in all fertilizer treatment is within the ideal value (<1.10 g cm^{-3}) for clay soils. But vermicompost showed the lowest value at both growth stages and also exhibited the highest decline at 60 DAS (Table 4). A low bulk density indicates that soil is porous and therefore the movement of air, water and solutes through the soil horizon is not restricted. Since water infiltration is not restricted, organic carbon may be carried along with the water into the lower soil horizon, hence reducing SOC at the upper 0-25 cm horizon. The result suggests that the application of vermicompost improves soil structure, which will be beneficial in the long run because this will influence better organic matter accumulation and consequently higher SOC (FAO 2005).

Dry Season Experiment

Plant Carbon Sequestration

During the dry season, inorganic fertilizer consistently produced the highest root, shoot and total plant carbon sequestration in all the monitoring periods. At 60 DAS, there was a significant increase in total plant carbon sequestration for all fertilizer treatments due to the considerable increase in shoot carbon sequestration (Table 5). Results of tissue analysis showed almost the same carbon content for roots and shoots which confirms the role of shoot in carbon sequestration (Table 6). These results imply that shoot biomass contributes significantly to plant carbon sequestration. Total plant carbon sequestration remained high at 90 DAS but the increment from 60 DAS was small compared to the increment from 30-60 DAS.

The high carbon sequestration of plants in inorganic fertilizer was due to greater biomass production (Table 7). This also means that among the fertilizer treatments, inorganic fertilizer contributed more to carbon sequestration by promoting better plant growth and development. This was evident in the amount of carbon sequestered, which was twice or more than the amount sequestered by plants applied with vermicompost. However, considering the CO_2 emission during the production of urea, which is about 0.91 kg CO_2-eq kg^{-1} of urea or 2 kg CO_2-eq kg^{-1} of N from urea (Bentrup and Pallière 2014), this may reduce the overall contribution of urea to total plant carbon sequestration by about 273 kg CO_2-eq ha^{-1}. This emission does not even include transport and emissions due to ammonia and nitrate.

Between the two rates of vermicompost, applying 8 t ha^{-1} contributed more to plant carbon sequestration due to the higher biomass production. Increasing the rate to 10 t ha^{-1} failed to increase biomass production, hence the lower plant carbon sequestration. Mineral fertilizer are readily available for plant uptake so the effect on plant growth and biomass production is immediate. In contrast, vermicompost must first undergo mineralization before the nutrients becomes available for plant uptake. Moreover, nutrient release from composts in general is gradual. Due to this nature of organic amendment, plant growth is slower and as a result biomass production is also lower.

Between the two cultivars, USM Var 10 contributed more to plant carbon sequestration compared to Crystal (Table 5). Again this could be attributed to the

Table 4. Soil carbon sequestration using inorganic fertilizer and vermicompost at 30 and 60 days after sowing (DAS), 2012 wet season, Los Baños, Laguna, Philippines

	Bulk density (g cm^{-3})		Soil organic carbon content (%)		Soil organic carbon sequestration (Mg ha^{-1})	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Fertilizer treatment						
Control	1.23 a	1.07 a	1.172 a	1.168 a	36.03 a	31.24 a
Inorganic	1.24 a	1.09 a	1.179 a	1.258 a	36.54 a	34.28 a
Vermi (8 t ha^{-1})	1.19 b	1.04 a	1.013 b	1.103 a	30.13 b	28.67 a

Means followed by the same letter within columns are not significantly different using LSD at 5% level

Table 5. Root, shoot and total plant carbon sequestration of USM Var 10 (high-yielding variety) and Crystal (farmer-selected cultivar) at 30, 60 and 90 days after sowing (DAS), 2013 dry season, Los Baños, Laguna, Philippines

	Plant carbon sequestration (Mg ha^{-1})								
	30 DAS			60 DAS			90 DAS		
	Root	Shoot	Total	Root	Shoot	Total	Root	Shoot	Total
Fertilizer treatment									
Control	2.12 b	17.63 bc	20.00 bc	18.13 b	168.00 b	186.00 b	34.00 c	210.13 b	244.00 b
Inorganic	3.88 a	31.13 a	35.25 a	82.25 a	419.75 a	501.88 a	65.88 a	452.75 a	518.50 a
Vermi (8 t ha^{-1})	3.00 ab	21.88 b	24.88 b	27.75 b	220.75 b	248.25 b	44.25 b	238.75 b	283.00 b
Vermi (10 t ha^{-1})	2.38 b	16.0 c	18.25 c	21.88 b	196.75 b	218.50 b	35.75 c	218.63 b	254.38 b
Variety									
USM Var 10	2.75 a	20.06 a	22.94 a	51.31 a	285.38 a	336.44 a	52.13 a	306.94 a	359.13 a
Crystal	2.94 a	23.25 a	26.25 a	23.69 a	217.44 b	240.88 b	37.81 b	253.19 b	290.81 b

Means followed by the same letter within columns are not significantly different using LSD at 5% level

Table 6. Root and shoot organic carbon content of USM Var 10 (high-yielding variety) and Crystal (farmer-selected cultivar) at 30, 60 and 90 days after sowing (DAS), 2013 dry season, Los Banos, Laguna, Philippines

	Organic carbon content (%)					
	30 DAS		60 DAS		90 DAS	
	Root carbon	**Shoot carbon**	**Root carbon**	**Shoot carbon**	**Root carbon**	**Shoot carbon**
Fertilizer treatment						
Control	7.54 b	8.15 ab	8.52 ab	8.50 ab	8.58 ab	8.56 ab
Inorganic	7.68 b	7.85 b	8.47 ab	8.47 b	8.53 ab	8.53 b
Vermi (8 t ha^{-1})	8.22 a	8.33 a	8.44 b	8.57 ab	8.50 b	8.63 ab
Vermi (10 t ha^{-1})	7.60 b	7.28 c	8.62 a	8.62 a	8.68 a	8.68 a
Variety						
USM Var 10	7.53 b	6.62 b	8.47b	8.50 a	8.53 a	8.63 a
Crystal	7.99 a	8.19 a	8.55 a	8.57 a	8.61 a	8.56 a

Means followed by the same letter within columns are not significantly different using LSD at 5% level

higher biomass production. The growth and dry matter production of USM Var 10 with inorganic fertilization was remarkably better than Crystal, thus resulting to considerably higher root, shoot and total plant C sequestration. Unlike Crystal, USM Var 10 is a high yielding variety developed for inorganic farming.

The amount of carbon sequestered in all fertilizer treatments represent the amount of CO_2 emitted into the atmosphere if the stover is not incorporated or plowed back into the soil after each cropping. Improving crop growth and biomass production through increased photosynthesis will increase CO_2 sequestration, which in turn will contribute to reducing atmospheric CO_2 concentration. Despite the low nutrient content of vermicompost and smaller contribution to plant carbon sequestration, it can still contribute to minimizing CO_2 since its use as organic amendment causes carbon to stay bound to soil (Sánchez et al. 2015). Moreover, unlike mineral fertilizers that are imported, vermicomposts are produced locally, hence CO_2 emission due to long distance transport is also minimized.

Soil Organic Carbon Sequestration

The soil organic carbon (SOC) for all fertilizer treatments increased from 30 to 90 DAS periods but the differences were not significant (Table 8). Plants were exposed to moisture deficit throughout most of their life cycle because of very little rain and insufficient irrigation water, resulting to low root biomass production. Decomposing roots and plant litter contribute to SOC concentration (Bot and Benites 2005). If root biomass production is low, and root turnover is low due to inefficient root decomposition, this will contribute little to SOC concentration.

Adequate moisture is essential for efficient root decomposition (Bot and Benites 2005). Due to the moisture deficit during the experiment, root decomposition would be slower. Moreover, roots degrade or decompose longer and therefore gradually transform to soil organic carbon (Rasse et al. 2005). A similar study reported no differences in SOC concentrations across N application of 0, 67, 135, 202 and 269 kg N ha^{-1} y^{-1}, suggesting that either crop residue inputs and C mineralization effect of N fertilization were equivalent or that soils were C saturated (Brown 2013).

Table 7. Total dry matter of USM Var 10 (high-yielding variety) and Crystal (farmer-selected cultivar) at 30, 60, and 90 days after sowing (DAS), 2013 dry season, Los Baños, Laguna, Philippines

	Total dry matter (kg ha^{-1})		
	30 DAS	**60 DAS**	**90 DAS**
Fertilizer treatment			
Control	243.11 b	2359.9 b	3293.0 b
Inorganic	435.56 a	5827.0 a	6122.9 a
Vermi (8 t ha^{-1})	282.45 b	2540.8 b	3575.7 b
Vermi (10 t ha^{-1})	241.56 b	1995.6 b	3249.9 b
Variety			
USM Var 10	289.5 a	3470.9 a	4391.7 a
Crystal	311.83 a	2890.7 b	3729.1 b

Means followed by the same letter within columns are not significantly different using LSD at 5% level

Bulk density (BD) values were similar regardless of the fertilizer treatment, although relatively lower values were observed under vermicompost treatment (Table 8).

The ideal BD of <1.10 g cm^{-3} was observed in all fertilizer treatment but only up to 60 DAS. Towards the end of the crop cycle, BD values increased beyond the ideal level.

A high BD indicates that the soil is compact and has low porosity and may cause restrictions to root growth resulting to poor plant growth. Restricted root growth can lead to low root biomass production. With low root biomass production and inadequate moisture to hasten root decomposition, very little carbon will be added to the soil. These conditions could have contributed to the lack of significant differences in soil organic carbon sequestration among the fertilizer treatments and between cultivars.

Table 8. Soil carbon sequestration using inorganic fertilizer and vermicompost at 30, 60 and 90 days after sowing (DAS), 2013 dry season, Los Baños, Laguna, Philippines

	Bulk density (g cm^{-3})			Soil organic carbon content (%)			Soil organic carbon sequestration (Mg ha^{-1})		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Fertilizer Treatment									
Control	1.10 a	1.04 a	1.19 a	0.96 a	1.11 a	1.04 a	26.40 a	28.90 a	30.94 a
Inorganic	1.10 a	1.00 b	1.20 a	1.07 a	1.16 a	1.02 a	29.40 a	29.0 a	30.60 a
Vermi (8 t ha^{-1})	0.96 b	1.04 a	1.16 a	0.97 a	0.94 a	0.99 a	23.28 a	24.40 a	28.70 a
Vermi (10 t ha^{-1})	0.99 ab	1.02 a	1.13 a	1.03 a	0.98 a	1.05 a	25.50 a	24.99 a	29.70 a

Means followed by the same letter within columns are not significantly different using LSD at 5% level

Summing up the total C sequestered both below- and above-ground, inorganic fertilizer contributed the most to C sequestration with an equivalent amount of 1,904 Mg CO_2-eq ha^{-1}, followed by 8 t ha^{-1} vermicompost with 1040 Mg CO_2-eq ha^{-1}.

CONCLUSION

High-yielding corn cultivars such as the USM Var 10 contributed more to plant C sequestration due to their inherent higher biomass production. The application of inorganic fertilizer further increased the plant carbon sequestration of this cultivar promoting plant growth and consequently biomass production. Although the growth of Crystal was also promoted with the application of inorganic fertilizer, its response was not as substantial as USM Var 10, thus its capacity for carbon sequestration was lower. The combined carbon sequestration from plant biomass production and soil carbon accumulation with inorganic fertilizer application was 1,904 Mg CO_2-eq ha^{-1} while that of vermicompost contributed to carbon sequestration of 935 to 1040 Mg CO_2-eq ha^{-1}.

The total carbon sequestration using inorganic fertilizer was undeniably much greater than using vermicompost. However, considering the various e nvironmental impacts of inorganic fertilizer, i.e., CO_2 emission during its manufacture, transport, and use; deterioration of soil and water quality; and impact on human health, this reduces its potential capacity to sequester carbon. Vermicompost can be a suitable alternative for its indirect positive effect on carbon sequestration. It improves soil health and causes carbon to stay bound to the soil thereby improving soil structure and promoting better root growth. In the long run, the continuous improvement in soil quality due to organic amendment may be translated to improved crop growth and biomass production, which in turn will contribute to greater carbon sequestration.

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