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Greenhouse-temperature induced manure driven low carbon footprint in aquaculture mesocosm

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Abstract

In an aquaculture system, estimates were made of soil organic carbon content, carbon burial rate, soil structure and algal productivity with the intention of examining the synergistic effects of both greenhouse gas (GHG) induced temperature and manure-driven carbon reduction potentials in sediments that depend on productivity as well as tilapia spawning responses under greenhouse mimicking conditions during winter. Different manure treatments such as cattle manure and saw dust (T1); poultry droppings and saw dust (T2); vermi-compost and saw dust (T3); mixture of cattle manure, poultry droppings, vermi-compost and saw dust (T4); iso-carbonic states maintained with vermi-compost (T5); and with poultry droppings (T6) were applied three times (frequency of application) in the tank during the course of investigation. Different parameters like soil organic carbon, carbon burial rate, algal productivity and water quality were examined in aquaculture system. GHG effect impacted on the enhanced carbon reduction potential (44.36-62.36%) which was directly related with soil organic carbon (38.16-56.40 mg C/g) dependent carbon burial rate (0.0033-0.0118 g/cm^2 per 100 days). Average carbon burial rates for different manure treatments at GHG impacted temperature (0.0071 g/cm^2 per 100 days) was as high as 27.90% than at ambient air temperature (0.0054 g/cm^2 per 100 days). Residual carbon or sink in soils has been increased by 8.49 to 43.11% in different treatments or 23%, on an average attributed to almost 6 °C rise in GHG mediated atmospheric temperature. The low carbon footprint potential in different treatments was conspicuous inside the polyhouse (maximum 62.36%) due to greenhouse driven temperature compared. As a positive impact of the study, breeding of tilapia occurred where in T3 100% survival occurred in close polyhouse and also exhibited maximum carbon burial rate. In this study it has been observed that one degree rise in atmospheric temperature resulted in a ~4% rise in residual carbon in the experimental tank. However, future work can be conducted on other different treatments and large scale application.

Highlights

- Raised temperature impacted enhanced decomposition of manure.
- Synergistic effects of temperature and GHG increase the primary productivity.
- Simulated mesocosm induced the spawning of fish tilapia during winter.
- Carbon burial rates at GHG impacted treatments were 27.90% higher.
- Carbon reduction potential of soil was enhanced by about 23% due to GHG effect.

Keywords: Aquaculture, Carbon burial, Low carbon footprint, Manure treatment, Soil organic carbon

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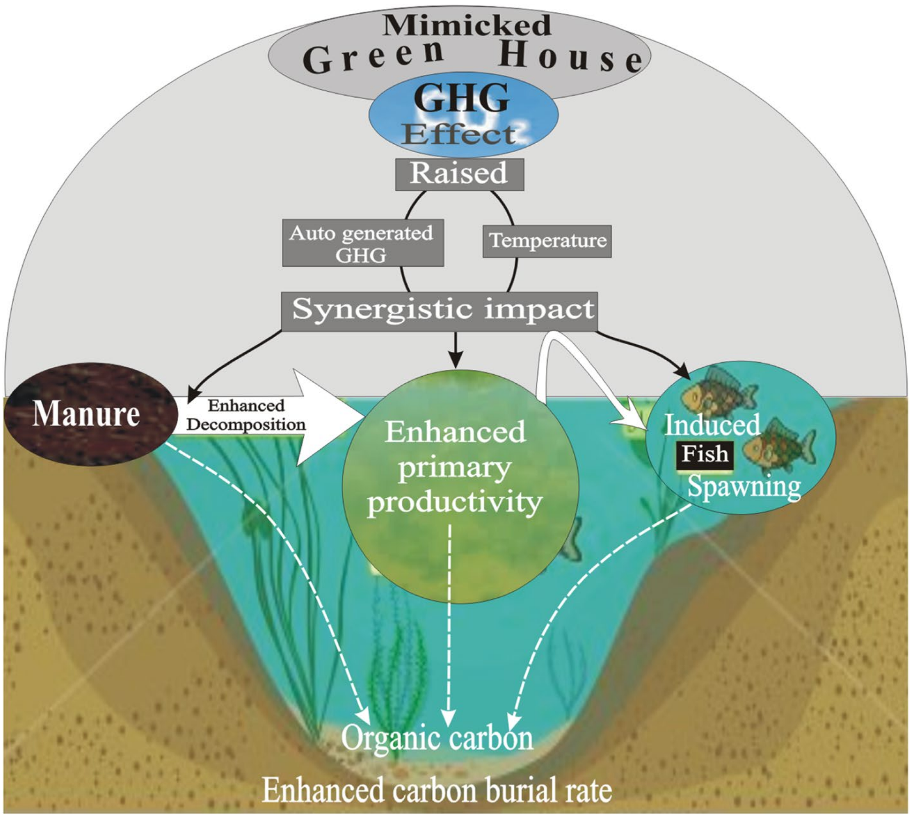
Graphical Abstract

Graphical representation of greenhouse-temperature induced manure driven carbon accumulation in aquaculture mesocosm.



1 Introduction

World has witnessed the disastrous consequences of anthropogenically induced GHG and climate change resulting in a 42.8% increase of carbon dioxide since industrialization (Kundu et al. 2021). GHG emissions from agricultural land use contributed 19-20% to global GHG emissions, including those from chemical fertilizer and land preparation and intensive tillage (Rahman et al. 2021). Aquaculture ponds stocked with freshwater bream (*Megalobrama amblycephala*) exhibit GHG emissions and greenhouse effect potential of 15.86 t CO_2/hm^2, suggesting their ability to contribute to global warming (Zhu et al. 2016). Changing climate is a vital social issue which can be managed by the combination of reduced emissions and mitigation strategies by enhancing natural carbon (C) storage in the ecosystem, i.e., biosequestration. In the global cycling of carbon, carbon dioxide moves from atmospheric pool to producers to consumers and from both of these groups to decomposers mediated through microbial loop and then returns to the pool again (Cavicchioli et al. 2019). Carbon sequestration is a process by which carbon sinks remove carbon dioxide from the atmosphere. The major steps of transformations involve: emission, evasion, capture, sequestration and storage in soils of terrestrial and aquatic ecosystems (Keenor et al. 2021).

The role of wetlands in carbon capture and storage has generally been underestimated despite their immense potentials in global cycling of carbon (Hilmi et al. 2021). Carbon performances of aquaculture ponds are generally well acclaimed. For the 7.4 million tons of global CO_2 emissions, terrestrial biosphere sequest 2 billion tons whereas oceanic uptake sequesters 2 ± 0.8 billion tons, and algae can fix 0.36 tons of carbon (Fawzy et al. 2020; Dutta et al. 2022). Algal photosynthesis has been accountable for about 50% of the global carbon fixation (Chen et al. 2016). Carbon burial rates in aquaculture ponds stocked with different species of fish ranged from 0.0028 g C/cm^2/yr to 0.0318 g C/cm^2/yr across the world (Table 1). Estimations revealed that approximately 17.2 Tg of carbon worldwide is annually buried from 11.1 million hectares (Mha) of aquaculture ponds (Adhikari and Lal 2017). In other words, carbon sequestration by aquaculture ponds is about 0.21% of the annual global C emissions or about 10 Pg/year (1Pg = Pentagram = billion ton). Sediment organic carbon deposition and accumulation in farm ponds particularly in small holding units is of special interest because they are of anthropogenic structures and used widely for rearing of indigenous fishes with heavy input of manure. Evidently, the volume of sediment deposited per unit time varied as a function of watershed size, being greater deposition and accumulation in smaller impoundments (Downing et al. 2008). The mean CH_4 emission tripled from 140 to 400 mg CH_4/m^2/d in constructed wetlands due to increased plant biomass and an average temperature increase of 3 °C within 10 years (Liikanen et al. 2006). Whilst incubating after addition of five nitrate concentrations (0, 1, 3, 8 and 16 mg NO_3^-–N per litre) in homogenized sediment sample collected from a constructed pond in Southern Sweden at 13 and 20 °C, Stadmark and Leonardson (2007) observed higher net production of N_2O at higher temperatures and increased NO_3 concentrations had strong positive impact on the N_2O concentration, but no effect on CH_4 and CO_2 production.

Conversion of CO_2 to organic matter through biological processes is a promising solution (Bhakta et al. 2015). Nutrient fertilization plays an important role in carbon cycle, and thus has a significant effect on atmospheric carbon dioxide concentration. Nutrients enrichment through manures, fertilizers, and other organic agricultural waste in the water body influences the growth of primary productivity which is associated with the carbon uptake over total area of aquatic system (Blain et al.

Table 1 Carbon burial rates in different aquaculture ponds

Location	Culture systems	Carbon burial rate (g/cm^2/yr)	Reference
Chiangrai, Thailand	Tilapia	0.0154	Thunjai et al. (2004)
Samutprakarn, Thailand	Tilapia	0.0076	Thunjai et al. (2004)
Khao Chakan, Thailand	Shrimp	0.0274	Boyd et al. (1999)
Sakaew, Thailand	Carp	0.0163	Boyd et al. (1999)
Suphan Buri/Sara Buri, Thailand	*Clarias* (catfish)	0.0064	Wudtisin and Boyd (2006)
Suphan Buri/Sara Buri, Thailand	Freshwater prawn	0.0028	Wudtisin and Boyd (2006)
Suphan Buri/Sara Buri, Thailand	Carp	0.0318	Wudtisin and Boyd (2006)
Abassa, Egypt	Tilapia	0.0115	Munsiri et al. (1996)
Lonoke, Arkansas, USA	Bait minnow	0.0076	Tepe and Boyd (2002)
Lonoke, Arkansas, USA	Bait minnow	0.0052	Tepe and Boyd (2002)
Lonoke, Arkansas, USA	Bait minnow	0.0044	Tepe and Boyd (2002)
Orissa, India	a) Polyculture of Indian major carps + scampi (organic fertilizer)	0.01530	Adhikari et al. (2012)
	b) Polyculture of Indian major carps + scampi (organic + inorganic fertilizer)	0.01463	Adhikari et al. (2012)
	c) Scampi (organic fertilizer)	0.00863	Adhikari et al. (2012)
Kalyani, West Bengal, India	a) Tilapia breeding during winter (cattle manure and saw dust)	Ambient air temperature - 0.0087	Present Study
		Green house temperature - 0.0146	
	b) Tilapia (poultry droppings and saw dust)	Ambient air temperature — 0.0133	Present Study
		Green house temperature - 0.0183	
	c) Tilapia (vermi-compost and saw dust)	Ambient air temperature - 0.0265	Present Study
		Green house temperature - 0.0342	
	d) Tilapia (mixture of cattle manure, poultry droppings, vermi-compost and saw dust)	Ambient air temperature -0.0376	Present Study
		Green house temperature - 0.0431	
	e) Tilapia (iso-carbonic states maintained with vermi-compost)	Ambient Air temperature - 0.0225	Present Study
		Green house temperature - 0.0302	
	f) Tilapia (iso-carbonic states maintained with poultry droppings)	Ambient air temperature - 0.0108	Present Study
		Green house temperature - 0.0122	

2007; Adhikari et al. 2012). Research of Blain et al. (2007) put new light on carbon sequestration by applying long-term iron fertilization and macronutrients in Southern Ocean. It is hypothesized that global warming caused by greenhouse gases would enhance the atmospheric temperature that would influence the sedimentation and carbon accumulation rates of the soil mediated through algal growth performance. It is likely that manure driven carbon burial rate would differ under the impact of greenhouse gases. Although global soil carbon stocks are fairly well characterized for upland soils (Minasny et al. 2017) and natural lakes (Probst 2005), lack of information exists about in situ carbon storage in wetland soils (Bridgham et al. 2006), especially in small holding tanks. Hardly any information is available on the impact of greenhouse gases on carbon storage or carbon sink in small pond soil. Gap in the literature about the manure driven sediment organic deposition and accumulation in the bottom sediment in small holding tanks motivated this research to examine the effects of different manures under simulated greenhouse conditions that synergistically induced the breeding of fish tilapia (*Oreochromis niloticus*) during winter. Results could be used to quantify and develop a model of the sedimentation dependent accumulation of organic carbon in a small holding unit (mesocosm) under simulated greenhouse condition.

The objective of the present investigation was to examine the impact of the increasing temperature on the sedimentation rate and carbon accumulation rate of soil. This concept was tested in an aquatic environment using polyhouse enclosure as greenhouse model. Recent studies suggest that strategic management of aquatic bodies may play an immense role in the global carbon capture and storage.

2 Materials and methods

2.1 Experimental set up

The experiment was performed during winter using 36 aquaculture mesocosms (small holding units-300 L) that were placed in equal numbers inside and outside the enclosed engineered polyhouse (conventional bamboo and covered with standard transparent polythene) that mimicked greenhouse functions. The effects of GHG emissions parameters were measured in terms of air temperature, light intensity and atmospheric CO_2 inside the constructed polyhouse (the simulated greenhouse) using the digital thermometer, LUX meter and CO_2 meter (Lutron GCH- 2018).

All the units were provided with 18 cm soil at the bottom, filled with aerated ground water (pH 7.2-7.4) and allowed for a week for establishment. Different organic manures such as cattle manure (CM) (T1), poultry droppings (PD) (T2), vermi-compost (VC) (T4) and saw dust (SD) were procured and used in different combinations to create specific treatment conditions (Fig. 1). To test whether saw dust could serve as the main carbon source for vermi-compost (T5), as well as low carbon and low nitrogen for poultry droppings (T6), it was necessary to establish such an iso-carbonic state with cattle manure. The source of carbon and nitrogen in the tank as mentioned in Fig. 1 was the applied manure. Among all the applied materials, carbon percentage of saw dust was the highest while poultry manure was designated as highest nitrogen contributor in the system. Hence, by combing different materials, a number of treatment conditions were created where carbon and nitrogen content were varied. Thus, the application of these varied combinations of manure were the input source of carbon and nitrogen in the system. The required amount of manure

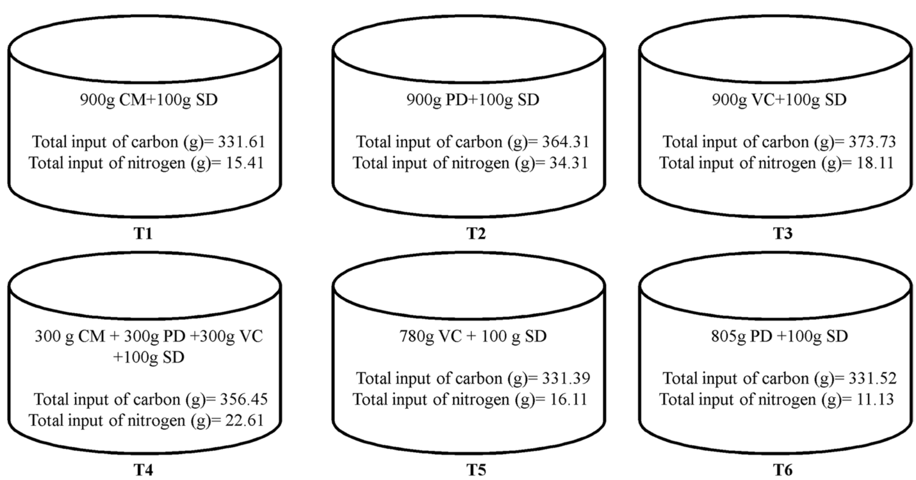


Fig. 1 Doses of manures used in different treatments maintained inside and the outside constructed greenhouse

was applied in each treatment tank prior to the establishment of microalgae followed by three subsequent installments applied on day 0, 35 and 75 of treatment. Healthy and adult male (8) and female (8) tilapia (*Oreochromis mossambicus*) were procured and introduced in each tank with a sex ratio of 1:1. The fishes were reared for 100 days without application of supplementary feed; manure driven algal food and detritus formed the main sources of food for the fish.

2.2 Collection and analysis of samples

Samples of soil and water were collected from each tank at regular intervals (3 days) during the grow out period of 100 days. The samples of soil and water were analyzed for different parameters (primary productivity, organic carbon, bulk density, particle density, total porosity, water holding capacity). The experiments were conducted three times.

Primary productivity was measured based on the Light and Dark bottle Method (Gaarder and Gran 1927). For the experiment two sets of Biological Oxygen Demand (BOD) bottle were prepared – one set as the Light bottle (LB) and the other one as the dark bottle (DB). Water samples were collected in both bottles from the same depth and location. Water collected in some of the LBs were fixed for chemical determination of initial dissolved oxygen with 1 ml manganous sulfate and 1 ml alkaline iodide solutions, and then brought into the laboratory. DB and some of the LBs were suspended at the desired depth tied on a bamboo poles or wooden planks alternately for incubation for a half photoperiod (at least 6 hr.). The light and dark bottles were suspended for one to several hours upto 12 hr., though 6 hr. period is generally preferred. Bottles were removed at the end of the test period and dissolved oxygen (DO) content was estimated. The productivity calculation was based on the following formula:

$$\text{Respiration [R]} = \text{Initial DO} - \text{Dark bottle DO (DBDO)} \tag{1}$$

$$\text{Gross Production [GPP]} = \text{Light bottle DO} - \text{DBDO} \tag{2}$$

$$\text{Net Production [NPP]} = \text{Gross primary productivity} - \text{Respiration} \tag{3}$$

Soil organic carbon was measured following the protocol mentioned by Nelson and Sommers (1975). For the estimation, 1.0 g of sample was weighed and added into a 250 ml digestion tube, and then 15 ml digestion mixture was added. Then the mixture was placed on a 150 °C pre heated block digester for 45 minutes. After cooling, 50 ml H_2O, 5 ml 85% H_3PO_4 and four drops of indicator were added. Titration was carried out using FAS for a colour change from dark violet green to light green with N-phenylanthranilic. Soil organic carbon was calculated using the following formula.

$$\text{Mg C in sample} = ((B - T)) \times (M) \times 0.003 \times 1000 \tag{4}$$

Where B and T are the titers of the heated blank and sample respectively and M is the molarity of the ferrous solution.

The sedimentation rate of suspended particles was determined by placing the Petri dishes at the bottom of each tank in the beginning and removed carefully at the end of the experiment. The weight differences of Petri dishes between the initial and final represent the sedimentation rate per unit area (Yousef et al. 1994).

The soil carbon burial rate was estimated from sediment accumulation rate, dry bulk density, and percentage organic C in sediment following the calculation as follows (Sasmito et al. 2020):

$$\text{Soil carbon burial rate} = \text{Soil sedimentation rate} \times \text{Soil bulk density} \times \%\text{of Soil organic carbon} \tag{5}$$

Residual carbon or carbon sink or low carbon footprint potential was estimated for each treatment using the difference between the total input and output C as shown below.

$$\begin{aligned}&\text{Total Input C } [\text{TIC} = \text{Manure C (MC)} + \text{Initial Soil Organic C (ISOC)} + \text{Initial Water Inorganic C (IWIC)} + \text{Initial Body Carbon of Fish (IBCF)}] \text{ and}\\&\text{Total Output C } [\text{TOC} = \text{Final Soil Organic C (FSOC)} + \text{Final Water Inorganic C (FWIC)} + \text{Autotrophic Production C (APC)} + \text{Final Body Carbon of Fish (FBCF)}]\end{aligned} \tag{6}$$

Water inorganic carbon was estimated from free CO_2, water carbonate and bicarbonate concentration by the calculation through their molecular weights. Low Carbon Footprint Potential (LCFP) was calculated as:

$$\text{LCFP (\%)} = \text{Residual carbon/Output carbon x 100} \tag{7}$$

All the data were statistically evaluated; analysis of variance in the form of split plot model (Næs et al. 2007; Maceina et al. 1994) was applied to identify the effects of treatments, time and interactions, if any. In this model, individual tanks were considered as whole plot treatment and time as subplot and significance test was evaluated at $p < 0.05$.

2.3 Gonado somatic index (GSI) calculation

All the harvested fishes were dissected out and their gonads were removed. The total weights of the ovary or testis were recorded and the GSI was calculated using the formula:

$$\mathrm{GSI} = \frac{\text{Weight of the gonad}}{\text{Total body weight of the fish}} \times 100 \tag{8}$$

3 Results and discussion

3.1 Light intensity, temperature and CO_2

It is more typical for the intensity of light to vary in the closed polyhouse when compared with the open system. The values of light intensity in the closed polyhouse ranged from 145 LUX to 340 LUX which is very high, whereas the values of light intensity in the open system ranged from 198 LUX to 580 LUX. The mean average light intensity of the closed polyhouse is 283 LUX in comparison with the open system that has an average of 485 LUX. The intensity of light was attenuated by 200% inside the constructed greenhouse. In the outdoor environment, photosynthesis makes light one of the most vital conditions for plant growth. The amount of light available to plants in greenhouses is affected by covering materials like polysheet, which are difficult to meet their light requirements (Xin et al. 2019). Hence, the light intensity inside polyhouse chamber may facilitate in the primary productivity inside the tank.

The temperature varies more characteristically in the closed polyhouse when compared with the open atmospheric temperature. The air temperature inside the polyhouse ranged from 25 °C to 45 °C against 21 °C to 36 °C ambient temperature outside ($F_{1,\ 32}=42.52$; $P \leq 0.001$). The overall mean air temperature inside the polyhouse (39 °C) remained more than 9 °C higher than the open system (29.5 °C). In the polyhouse, the covering material adversely affected microclimates such as temperature and humidity. A transparent polyhouse surface allows solar energy to enter during the daytime to raise its temperature (Kim et al. 2022).

The CO_2 level varies distinctively in the closed polyhouse when compared with the open ones. The values of CO_2 in the closed polyhouse ranged from 490 ppm to 920 ppm which is very high, whereas the values of CO_2 in the open system ranged from 360 ppm to 440 ppm ($F_{1,\ 32}=42.52$; $P \leq 0.001$). The mean average carbon dioxide level of the closed polyhouse is 705 ppm in comparison with the open system having an average of 408 ppm. Study of Hernández-Hernández et al. (2018) suggest that increase in atmospheric CO_2 level enhance the primary productivity and chlorophyll content in aquatic body. It is evidence that, net photosynthesis increases when CO_2 levels increase from 340 to 1000 ppm.

Water temperature in all treatments ranged from 18 °C to 32 °C under open condition and from 22 °C to 38 °C under the simulated greenhouse condition. The average minimum and maximum temperature for all treatments inside the polyhouse remained 22% and 18% higher than their counterparts placed outside. Clearly, this difference was due to greenhouse effects.

3.2 Organic carbon and carbon burial rate

The organic carbon content of the soil ranged from 25.99 mg C/g to 38.65 mg C/g and 23.85 mg C/g to 31.36 mg C/g in the treatments maintained under closed and open system, respectively. All the treatments maintained in the enclosed polyhouse showed higher values of organic carbon than their open counter parts (Fig. 2). Estimated organic carbon in the sediment was maximum in case of mixed manure (T4) under closed condition and minimum in the T1 with cattle dung in the open system. However, the differences between the closed and open system was maximum in mixed manure (T4) and minimum in vermi-compost (T3). This shows that mixed manure served as carbon sink at a much faster rate than vermi-compost under similar condition of enclosed polyhouse. This is obvious because of the differences in the chemical composition of the two manures. This signified the impact of GHG induced temperature dependent manure decomposition and carbon accumulation and deposition. It is likely that the allochthonous or autochthonous materials such as organic particles, detritus, dead plankton, fish excrements are deposited and eventually get buried in the sediment representing carbon sink or short or long term sequestration of atmospheric carbon dioxide. The increase of autochthonous production and allochthonous loading often result in elevated organic carbon and nitrogen accumulation rates in sediment (Huang et al. 2017). The aquatic microorganisms play a key role in the carbon mineralization and trophic chain is mediated through microbial carbon loop mechanism, whilst autotrophs are responsible for the carbon input to the ecosystems (Amado and Ronald 2017). However, it is not yet clear how the heterotrophs contribute to carbon retention and emission especially from tropical aquatic ecosystems (Amado and Ronald 2017).

Sediment organic matter dependent carbon burial rates in all the treatments attributed to GHG effects (0.0033 g/cm^2 to 0.0118 g/cm^2 per 100 days) against 0.0024 g/cm^2 to 0.0103 g/cm^2 per 100 days (Fig. 3). Carbon burial rates in aquaculture ponds stocked with different species (Table 1) were found to range from 0.0028 g/cm^2/yr in freshwater prawn ponds to 0.0318 g/cm^2/yr in carp ponds (Wudtisin and Boyd 2006). It is further revealed that regardless of exposure condition, the mixed manure (T4) experienced the highest carbon burial rate coupled with

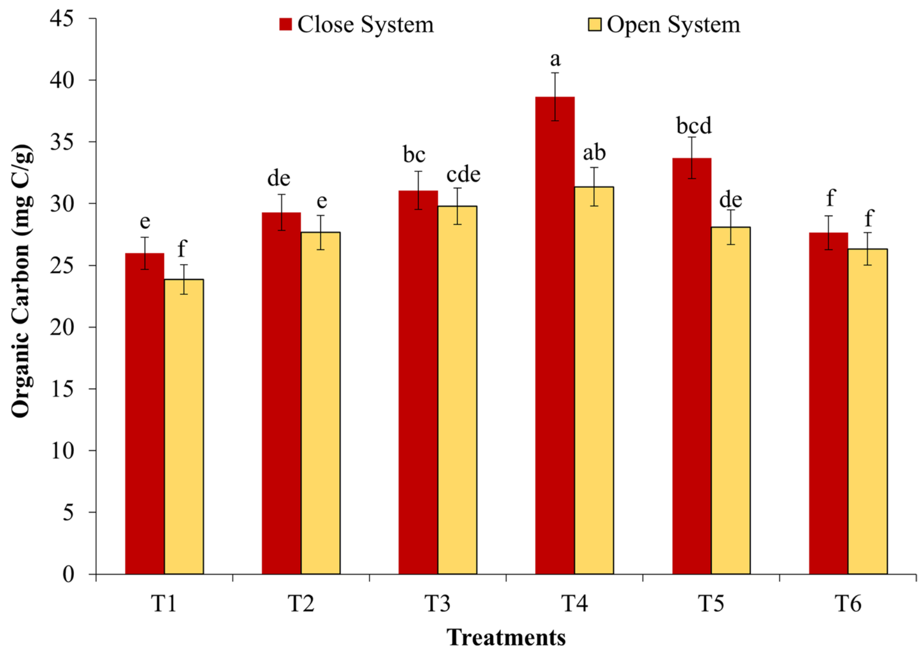


Fig. 2 Variation of accumulated organic carbon in greenhouse and ambient air temperature system employed

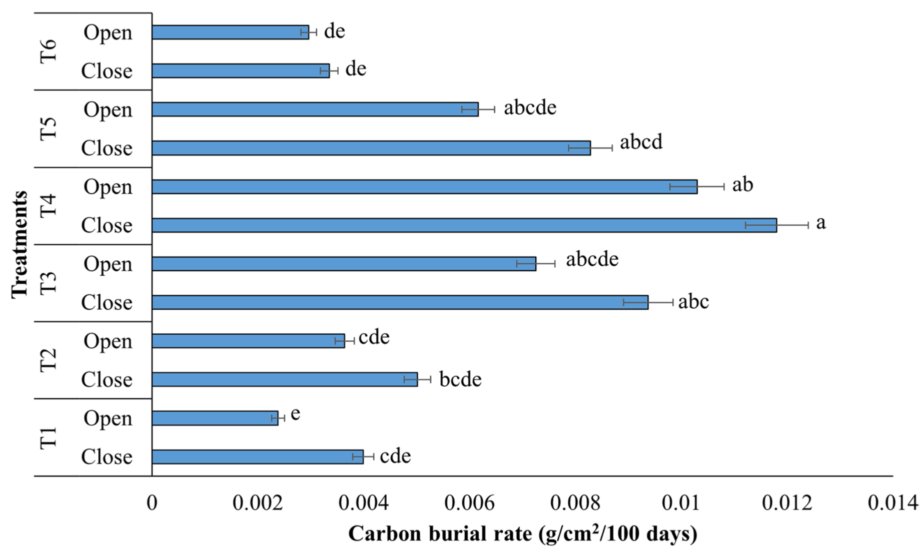


Fig. 3 Variation of carbon burial rate of different treatments under close and open condition

maximal primary productivity of microalgae among all the treatments. The average increment of carbon burial rate inside the greenhouse (0.007 g/cm^2 per 100 days) was 27.90% higher than those maintained outside (0.0054 g/cm^2 per 100 days) apparently due to GHG effects. This fairly shows that sediment organic carbon burial rate was the direct function of allochthonous induced autochthonous primary production and that was further enhanced in the enclosed polyhouse due to greenhouse effect. It is proposed that the greenhouse driven raised temperature triggered the microbial activity dependent manure decomposition as well as enhanced primary productivity of phytoplankton, which in turn coupled with GHG driven raised temperature synergistically induced the breeding and spawning of tilapia. Hence, the accelerated metabolic activities of pond ecosystem were responsible for the higher values of organic carbon and carbon burial rates in sediments of all treatments under greenhouse condition than under ambient temperature system. In ponds stocked with catfish, freshwater prawn and carp in Thailand, the amount of organic carbon was up to 5.07%. The optimum organic carbon range in pond sediments has been reported to be 1-3% (Wudtisin and Boyd 2006). Further, it is known that sediment deposition and accumulation rate in natural lakes and watersheds are regulated by the watershed size and lake area (Downing et al. 2008). The greatest burial of erosional materials has been recorded in small impoundments (Smith et al. 2002). Sobek et al. (2009) compared the burial efficiency of organic carbon (buried OC: deposited OC) among 11 lakes and found that average OC burial efficiency was quite high (mean 48%) and was related with the input of allochthonous organic matter.

3.3 Soil structure

There was no marked difference in the bulk density of the soil ranging from 0.64 g/cm^3 to 0.85 g/cm^3 and 0.64 g/cm^3 to 0.83 g/cm^3 in the treatments in the mimicked greenhouse and ambient treatment system respectively. All the treatments maintained in the enclosed polyhouse showed higher values of bulk density than their open counter parts except in treatment T1 with cattle dung. The rate of increase was higher in most of the treatments (T2, T3, T4, T5 and T6) under closed system than in open ones. Wudtisin et al. (2015) reported average bulk density of 0.77 ± 0.12 g/cm^3 and 0.86 ± 0.10 g/cm^3 in nile tilapia (*Oreochromis niloticus*) ponds and ponds with cages containing red hybrid tilapia (*Oreochromis niloticus* × *mossambicus*). The responses of particle density showed the same trend in the closed (1.52 g/cm^3 to 2.16 g/cm^3) and open systems (1.44 g/cm^3 to 2.12 g/cm^3). All the treatments maintained in the enclosed polyhouse showed higher values of particle density than their open counter parts except the treatment T2 that used poultry dropping. Similar to bulk density, the rate of increase was also higher in most of the treatments (T1, T3, T4, T5 and T6) under closed system than in open ones. Treatment-wise, both bulk density and particle density remained the highest and lowest in the treatments T4 and T1, respectively. The porosity of the soil did not differ much between closed (53.42% to 60.87%) and open (55.21% to 60.71%) systems. The treatments with cattle dung (T1), vermi-compost (T3), mixed manure (T4) and isocarbon with poultry droppings as basal (T6) showed higher percentages in the enclosed polyhouse compared with the open ones whereas the rest of the treatments (T2: poultry droppings and T5: isocarbon with Vermi-compost as basal) showed higher values in the open system. The magnitude of variations of water holding capacity of the soil was slightly higher (70.55% to 90.70%) in the treatments in the enclosed polyhouse than in the open (72.91% to 86.98%) system. The treatments with cattle dung (T1) and vermi-compost (T3) showed higher percentages in the enclosed polyhouse compared with the open ones. The treatments with poultry droppings (T2), mixed manure (T4), isocarbon with vermi-compost as basal (T5) and isocarbon with poultry droppings as basal (T6) showed higher values of water holding capacity in the open system than the closed polyhouse. With the increase of water holding capacity of soil in different treatments, the carbon burial rate of soil decreased exhibiting a reciprocal relationship between the two (Fig. 4).

3.4 Autotrophic production carbon

The level of primary productivity of phytoplankton was highly variable ranging from 32.33 mg/cm^2/hr. to 307.88 mg/cm^2/hr. in different treatments. Application of poultry dropping along with saw dust resulted in significantly higher values ($F_{5, 35} \geq 24.46$; $P < 0.001$) of GPP (Gross Primary Productivity), NPP (Net Primary Productivity) and community respiration and lower in the treatment T4 than the remaining treatments employed. Enclosed polyhouse induce the gross primary productivity of phytoplankton, NPP and CR than in open system ($F_{1, 42} \geq 42.51$; $P < 0.001$). Greenhouse drove almost a 6 °C rise in water temperature which triggered the manure decomposition and carbon content from productivity ranging from 171.10 mg C/m^3 to 241.07 mg C/m^3 in different treatments (ANOVA; $P < 0.001$). Similar responses were also encountered with the NPP and community respiration. The values of primary productivity of phytoplankton at the ambient air temperature remained distinctly lower than that of GHG impacted values. The results of the study further showed that greenhouse driven manure decomposition not only influenced sediment quality and primary productivity but also water quality (Jana et al. 2016). For example, an acidic condition more prevailed due to greenhouse effect. Likewise, the values of TDS and specific conductance were significantly higher (ANOVA; $P < 0.05$) in the closed polyhouse compared to the ambient temperature. On the contrary, the concentration of DO was greatly reduced due to greenhouse effect (Jana et al. 2016; Jana et al. 2019).

3.5 Survival and breeding of tilapia

Application of poultry droppings and saw dust (T2) resulted in total mortality or zero survival of fish within 10 days of introduction both inside and outside the polyhouse. Conversely, 100% survival was encountered in the

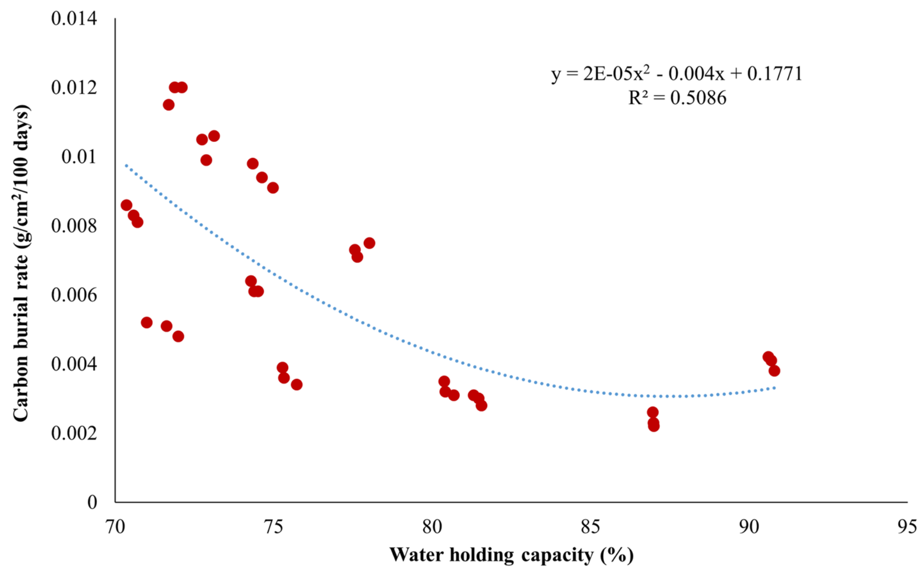


Fig. 4 Relationship between water holding capacity and carbon burial rate in different treatments employed

T3 treatment in the enclosed polyhouse, while the same treatment under open condition resulted in 36% mortality or 64% survival of fish introduced (Jana et al. 2019).

The average gonado somatic index (GSI) for either sex of tilapia remained higher under closed polyhouse than under ambient temperature system. Furthermore, the GSI of the male fishes was distinctly lower than that of the females due to the comparative investment of gonadal material in the former.

It has been previously proved (Jana et al. 2015) that polyhouse raised temperature induced tilapia to spawn earlier than under ambient temperature. The main contribution of the present study is that the number of fry produced varied depending upon the manure treatment under enclosed polyhouse. Lack of fry in all treatments under the open conditions implied that no breeding occurred under the ambient winter temperature. In the present study, the synergistic effects of manure driven water quality-food resource complex and temperature appeared to be pronounced than the impact of temperature alone in selecting the treatment that developed the total benign environment and induced tilapia to spawn even during winter.

3.6 Carbon reduction potential

Residual carbon content of the tanks inside the polyhouse were 22.44 to 43.11% higher than the tanks which were placed outside (Table 2). In this phenomenon T3 treatment was exempted where difference in residual carbon between inside and outside polyhouse tanks was less. This shows that about 6 °C increase in greenhouse mediated atmospheric temperature resulted in an average of 22.98% rise in residual carbon attributed to enhanced decomposition of organics of both allochthonous and autochthonous origin. This implied that one degree rise in atmospheric temperature would result in 3.83% rise in carbon reduction potential in small impoundment under intensive farming and manuring. As a result of applying manures, fertilizers, feed, and other agricultural wastes to ponds, phytoplankton photosynthesis is stimulated in ponds, and thus increases OC production. Unlike reservoirs or watershed ponds in agricultural or rural areas, aquaculture ponds do not have large external sediment loads. A pond's bottoms are gradually mixed with soil particles due to substances such as uneaten feed, organic fertilizers, and organic matter (OM) from dead plankton. However, OC concentrations in sediments in aquaculture ponds are higher than those in the original soil, despite these practices (Adhikari and Lal 2017). In the present study also decomposition of manure and dead algae has contributed to raise the bottom soil OC which was resulted from the higher temperature.

3.7 Low carbon footprint potential

Wetlands and farm ponds are considered as depositional environments; the materials that are deposited and accumulated in the bottom are of allochthonous or autochthonous origin in the form of organic particles, feed remnants, fish excrements, detritus, dead plankton, decomposed leave particles, etc. Regardless of the source, accumulated organic carbon eventually get buried in the

Table 2 Carbon Balance (kg C/m^3) between input and output of different treatments

		MC (Kg C/m^3)	ISOC (Kg C/m^3)	IWIC (Kg C/m^3)	IFC (Kg C/m^3)	Total input (Kg C/m^3)	FSOC (Kg C/m^3)	FWIC (Kg C/m^3)	FFC (Kg C/m^3)	APC (Kg C/m^3)	Total output (Kg C/m^3)	Low carbon footprint (−) (Kg C/m^3)	Low carbon footprint potential (%)
T1	**Open**	1.11	13.33	0.006	0.06	14.506	23.85	0.0239	0.082	0.00017	23.96	9.45	39.45
	Close	1.11	13.33	0.006	0.07	14.516	25.99	0.0219	0.075	0.00018	26.09	11.57	44.36
T2	**Open**	1.21	13.33	0.006	0.05	14.596	27.67	0.027	0	0.00023	27.7	13.1	47.3
	Close	1.21	13.33	0.006	0.09	14.636	29.29	0.0281	0	0.00024	29.32	14.68	50.08
T3	**Open**	1.25	13.33	0.006	0.07	14.656	29.79	0.0261	0.072	0.00019	29.89	15.23	50.96
	Close	1.25	13.33	0.006	0.05	14.636	31.07	0.0243	0.067	0.0002	31.16	16.53	53.03
T4	**Open**	1.19	13.33	0.006	0.07	14.596	31.36	0.0258	0.084	0.00016	31.47	16.87	53.62
	Close	1.19	13.33	0.006	0.05	14.576	38.65	0.0221	0.052	0.00017	38.72	24.15	62.36
T5	**Open**	1.1	13.33	0.006	0.06	14.496	28.1	0.0238	0.065	0.0002	28.19	13.69	48.58
	Close	1.1	13.33	0.006	0.07	14.506	33.7	0.0252	0.07	0.00019	33.8	19.29	57.08
T6	**Open**	1.11	13.33	0.006	0.06	14.506	26.33	0.0259	0.069	0.00017	26.43	11.92	45.11
	Close	1.11	13.33	0.006	0.06	14.506	27.64	0.0251	0.062	0.00018	27.73	13.22	47.68

MC Manure Carbon, *ISOC* Initial Soil Organic Carbon, *IWIC* Initial Water Inorganic Carbon, *IBCF* Initial Body Carbon of Fish, *FSOC* Final Soil Organic Carbon, *FWIC* Final Water Inorganic Carbon, *FBCF* Final Body Carbon of Fish, *APC* Autotrophic Production Carbon sediment over the course of time and represents carbon sink or short or long term sequestration of atmospheric carbon dioxide. The low carbon footprint potential in different treatments was conspicuous inside the polyhouse (44.36 to 62.36%) due to greenhouse driven temperature compared to ambient temperature system (39.45% to 53.62%). Treatment-wise, T4 experienced the highest carbon footprint potential both inside (62.36%) and in ambient temperature (53.68%) system. Thus, the low carbon footprint was more pronounced in the enclosed polyhouse than outside. It appears that GHG has positive effects when it comes to the ecosystem functional based manure driven culture system. This system appears to be beneficial for primary productivity and carbon sinks resulted from the sedimentation of organic particles and dead plankton, etc. (Oertel et al. 2016). This mixed manure combination appears to be an optimal option for maximal carbon reduction.

4 Conclusions

Simultaneous carbon evasion/emission and sequestration in a water body is an enigma of nature. As per the authors knowledge this is the first mesocosm study addressing the carbon accumulation potentiality of aquaculture system under increasing CO_2 concentrations, enhanced temperature and nutrient fertilization. Due to the significant role played by natural food chains induced by exogenous application of manure, ecosystem functional dependent culture practices are definitely going to be superior. Manures are decomposed and mineralized via microbial loop enhancing primary productivity, planktonic and detrital food chain and fish biomass. Decomposition of allochthonous manure, autochthonous dead particle and microalgal productivity was strongly triggered by an approximately 6 °C rise of atmospheric temperature due to the greenhouse effects. The significance of the study is that one degree rise in atmospheric temperature would result in almost 4% rise in residual carbon or carbon burial in impoundments under intensive farming and manuring. Based on the present study, it is evident that the soils of aquaculture ponds have a strong potential to sequester soil C. Increasing SOC pool in soils could offset emissions of CO_2 from fossil fuel combustion.

Abbreviations

GHG: Greenhouse Gas; CM: Cattle Manure; PD: Poultry Droppings; VC: Vermi-Compost; SD: Saw Dust; DO: Dissolved Oxygen; BOD: Biochemical oxygen demand; TIC: Total Input C; MC: Manure C; ISOC: Initial Soil Organic C; IWIC: Initial Water Inorganic C; IBCF: Initial Body Carbon of Fish; TOC: Total Output C; FSOC: Final Soil Organic C; FWIC: Final Water Inorganic C; APC: Autotrophic Production C; FBCF: Final Body Carbon of Fish; LCFP: Low Carbon Footprint Potential; OC: Organic Carbon.

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Authors' contributions

Deblina Dutta: Data curation, Formal analysis, Investigation, Validation, Writing – original draft; Debajyoti Kundu: Data curation, Formal analysis, Investigation, Validation, Writing – original draft, Writing – review & editing; Bana Bihari Jana: Writing – original draft, Conceptualization, Funding acquisition, Project administration, Supervision, Resources; Susmita Lahiri: Writing – review & editing; Jatindra Nath Bhakta: Writing – review & editing. All authors reviewed the results and approved the final version of the manuscript.

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Availability of data and materials

The datasets used or analyzed during the current study are incorporated in this manuscript.

Declarations

Competing interests

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