THE INTERNATIONAL JOURNAL OF
SCIENCE & TECHNOLEDGE

Effect of Moisture Content on Carbon Dioxide Emission from the Soil of Rice Fields in Raozan, Bangladesh

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Abstract:
Emission of CO_2 from rice fields contributes to global warming. However, CO_2 emission from the soil of rice fields varies with moisture content (MC) during different stages of rice cultivation: submerged (MC≥ 70 per cent), moistened (40 per cent MC), and fallow (20 per cent ≥ MC). Therefore, this study focuses on the effect of MC on CO_2 emission from the soil of rice fields and investigates if average moisture conditions support high CO_2 emission from soil. The research was conducted in three locations in Raozan, Bangladesh. Samples were collected from top soil (0-30 cm), where different stages of rice cultivation were observed. Organic carbon percentage (OC percentage), microbial biomass carbon (MBC), pH, and electric conductivity (EC) of samples were also tested. Results of the study implied that the highest CO_2 emission occurred from submerged soil as a consequence of anaerobic fermentation that favored CO_2 emission due to pH and high OC percentage. Also, the methane oxidation occurred as the submerged samples were exposed to oxygen (O_2) during the sampling and experimental process. CO_2 emission was lowest in fallow soil because of dry conditions that led dehydration of microorganisms. Moistened soil had an intermediate CO_2 emission due to low OC percentage. Therefore, the study suggests that the dry conditions of soil result in the least amount of CO_2 emission; hence, intermittent irrigation methods should be applied in rice fields to minimize the CO_2 emission and water consumption.

Keywords*: Soil, rice, carbon dioxide, emission, moisture content*

1. Introduction

Rice is consumed as a staple food by a half of the population in the world (Rashid at al., 2012). Besides wheat, it contributes to a significant amount of global food consumption as a cereal food (Satyanarayana & Thiyagarajan, 2007). Even though one hundred twelve countries from 53° North latitude to 35° South latitude over the globe partake in rice cultivation, 90 per cent of globally produced rice is cultivated and consumed in Asian region (The Cambridge World History of Food- Rice. 2014). For instant, China and India respectively poses the largest and the second largest output of rice production in Asia, while Bangladesh, Cambodia, Indonesia, Laos, Myanmar, Thailand, and Vietnam hold the highest per capita rice consumption among all the Asian countries (Integrated Breeding Platform, 2014).

However, rice fields have been a concern of the scientists in terms of greenhouse gas (GHG) emission since rice fields are responsible for emitting three major GHGs such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (N_2O) (Arunrat & Pumijumnong, 2017). CH_4 emission occurs due to methanogenesis process while N_2O emission is caused by the use of nitrogen fertilizers in rice fields (Arunrat & Pumijumnong, 2017). Even though researchers emphasize that CO_2 is released due to the anthropogenic activities in rice fields such as burning of crop residue and the use of energy for farm activities, it is evident that some amount of CO_2 is also released from the soil of rice fields due to the decomposition of soil organic carbon by microorganisms (Paustian et al., 2000; Majumder, & Kuzyakov, 2010). Yet, little is known about the emission of CO_2 compared to the emission of CH_4 and N_2O from the soil of rice fields (Boateng et al., 2017). In fact, this CO_2 emission can be influenced by physical and chemical condition of the soil such as moisture content (MC), pH, electric conductivity (EC), and aeration (Mosier, 1998). Amongst the factors that influence GHG emission from the soil of rice fields, MC can have a great influence on CO_2 emission since the MC varies significantly with different phases of the rice cultivation. Therefore, the objective of this study was to investigate the effect of moisture content on CO_2 emission from soil of rice fields. In order to execute the study, soil samples were collected from one of the rice growing countries, Bangladesh.

2. Literature Review

2.1. Rice Cultivated Environments

Three major types of rice cultivated environments exist in Asia: rain-fed, irrigated, and deepwater (Mondal et al., 2012). Rain-fed system highly depends on the rainfall during monsoon and is divided into two sectors such as rain-fed lowland and upland. Rain-fed lowland is the low elevated area and is subjected to floods, whereas the rain-fed upland system refers to high elevated areas, which also depend on monsoon rainfall (Papademetriou & Dent, 2001).

Irrigated system is mostly applied in dry lowland areas, where water supply is suitably controlled with properly managed cannels (Calpe, 2006). On the other hand, deepwater rice system is a common practice in areas that are situated in floodplains (Metraux, & Kende, 1982). For instance, deep water rice varieties grow in low-lying lands around dry river beds; later, floods cover these rice fields making them partly submerged. In each rice cultivated environments, local rice verities are cultivated depending on the growth condition of each variety (Papademetriou & Dent, 2001).

2.2. Cropping Systems and Patterns

Solely, rice field is distinguished into three main systems: single cropped, double cropped and triple cropped (Son et al., 2012). If a rice variety has a long-life time, for example, 160-180 days, that variety is cultivated as a single cropped system (Son et al., 2012). Also, single cropped rice varieties are cultivated in rain-fed lowland, coastal areas, and floodplains. In both the other cases, rice variety has a short life time and is cropped for two or three times a year. In addition to cropping systems, cropping patterns also exist.

With short-term rice varieties, other types of crops like vegetables, wheat, mustard, and the like are grown in appropriate seasons of the year (Mondal et al., 2012). For example, rice-wheat cropping pattern is adopted in Indo-Ganges floodplain in India, Bangladesh, Pakistan, and Nepal after the green revolution, where long duration rice and wheat varieties are developed into high yielding, photo insensate, short lifetime, and rich fertilizer approachable varieties (Hobbs & Morris, 1996). In addition to this pattern, twenty more other cropping patterns are practiced in the region depending on the characteristics of farm lands, preference of farmers, soil, and climate (Papademetriou & Dent, 2001**)**. For example, rice is cultivated mostly in monsoon season and other crops like potato, tomato, mustard and the like are cropped during winter in lowland in Bangladesh while Aman rice- fallow-Boro rice pattern is cultivated in 22 per cent of total cultivated areas (Rashid et al., 2012). Bangladesh Rice Research Institute (BRRI) encourages farmers to follow Aman-Mustard-Borrow patter to increase the oilseed production to meet the demand. As such, cropping patterns are subjected to much of diversification across the farmlands in different countries.

The importance of this cropping system is that it intensifies the organic matter in the soil that leads to soil fertility of land. Similarly, crop diversification is carried out to utilize the water resources to maximize the products from farmlands and to meet the food demands (Papademetriou & Dent, 2001).

2.3. Growth Cycle of Rice and Moisture Requirement of Each Phase

A rice plant goes through three phases during its lifetime: vegetative phase, reproductive phase, and maturity phase (Integrated Rice Management in Inland Valleys of Sub-Saharan Africa-Technical Manual, 2009). Vegetative phase includes seed germination, seeding emergence, leaf emergence, tilling, and increase in plant height. Duration of the vegetative period is about 65 days; however, this duration changes with the rice variety. Reproductive phase includes the changes that occur in the plant from the vegetative phase to flowering period of rice. Typically, reproductive phase takes thirty to thirty-five days regardless of the rice variety and the season. Lastly, maturity phase covers from flowering period to the harvesting period. Maturity phase also has a fixed duration, which is about thirty days.

Rice consumes 67 per cent of the global water withdrawal because rice has the lowest water use efficiency among all the cereal plants; therefore, rice plants require moisture rich environment to complete its life cycle (Doll & Siebert, 2002). During rice cultivation, land preparation requires the highest amount of water (Department of Agriculture-Government of Sri Lanka, 2006). The growth cycle of rice also needs adequate moisture content; however, the amount of moisture varies with the rice variety. Vegetative phase of the growth cycle is also susceptible to low moisture content of soil; low moisture content reduces the plant height, tiller number, and the leaf area. Moisture deficiency during the reproductive phase leads to the sterility of rice plants (Integrated Rice Management in Inland Valleys of Sub-Saharan Africa-Technical Manual, 2009). Similarly, moisture stress in the first half of maturity phase (first fifteen days) can harm the rice plants even though water stress does not have much impact on the rice plants and the yield during the second half. Hence, maintaining proper moisture contents (MC) in each phase provides favorable conditions for rice to grow and to produce a good yield (Department of Agriculture-Government of Sri Lanka, 2006).

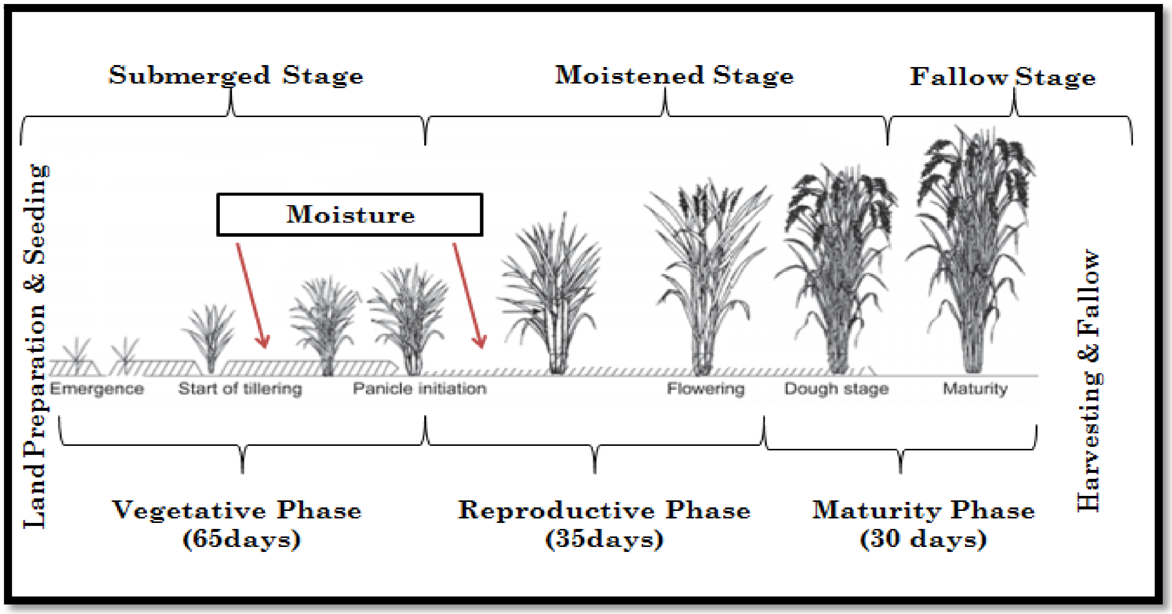

Figure 1: Phases of the Growth Cycle of Rice and Moisture Requirement of Each Phase (Adopted and Modified from Integrated Rice Management (IRM) in Inland Valleys of Sub-Saharan Africa-Technical Manual, 2009)

Considering the moisture requirement in each phase of the growth cycle of rice, the MC of soil can be divided into three periods: submerged, moistened and fallow (Figure 1). Mostly, soil remains submerged during land preparation and vegetative phase as these two phases require ample supply of water. During the reproductive phase and the first half of the maturity phase, an adequate amount of water supply is needed; hence, the soil is moistened. Second half of maturity phase and the fallow period require the least amount of water and fall under fallow period.

2.4. Co$_2$ Emission

Cultivation practices – leaving crop residue and rice plant shoots in the fields after harvesting – and crop diversification contribute to the enrichment of organic matter in the soil (Majumder, & Kuzyakov, 2010; Majumder et al., 2006). As a consequence, soil of agricultural lands, including rice fields; occupy more than 10 per cent of total carbon stock of the world (Paustian et al., 2000). This organic matter is then degraded and decomposed by soil microorganisms; during the decomposition process, soil organic carbon is mineralized into CO_2, causing CO_2 emission (Majumder, & Kuzyakov, 2010). For example, organic matter in soil acts as sites for microorganisms such as cyanobacteria, fungi, other soil microbes (Nayak & Prasanna, 2007). Their extra cellular polysaccharides bind with crop residue and soil particles forming macro-aggregates (Paustian et al., 2000). During the decomposition of these soil macro-aggregates, CO_2 is released from soil. For instant, mineralization of soil organic carbon of agricultural fields has been adding 50 Pg of CO_2 to the atmosphere (Paustian et al., 2000; Majumder, & Kuzyakov, 2010). Decomposition of labile carbon fraction of soil organic carbon releases more CO_2 to the atmosphere compared to the refractory pool, which is less susceptible for microbial activities (Majumder, & Kuzyakov, 2010).

3. Methodology

3.1. Sampling Site and Cultivation Practice

Soil samples were collected on 4th February 2014 from three locations: Sultanpur, Kundur Chori, and South Shapta of Raozan Upazila in Chittagong Bangladesh (22.53° N, 91.93° E). These locations were selected to have representative soil samples from Raozan Upazilla. Moreover, cultivation practices and soil texture of these three locations were not much distinct (Table 1) (Hasan, 2010). Each rice field was separated into two portions called lowland and upland in all three fields. Vegetables were grown in the upper land during winter season, while rice was cultivated during monsoon in both upper and lower land; hence, the rice cultivation was very much dependent on the monsoon rainfall.

Location Name	Cropping Pattern	Submerged Stage	Moistened Stage	Fallow Stage	Land Preparation	Rice Variety
Sultanpur	-Upper land: rice-vegetables-rice (vegetable is cultivated in winter) Lower Land: rice-fallow-rice	About five months including monsoon	Three months	One to two months	Plough with crop residue by using tractors. Then rice is transplanted with 6-inch plot size	IRRI, local Aman
Kundur Chori	Upper Land: vegetable-fallow-rice-fallow pattern Lower Land: fallows the rice-fallow-rice	Four to five months including monsoon	Three to four months	One month	Similar to Sultanpur	IRRI, local Aman
South Shapta	Upper Land: rice-vegetables-rice (vegetable is cultivated in winter) Lower Land: rice-fallow-rice	Less than a month including monsoon. Land is fed with water from nearby streams	About six months	Two months	Similar to sultanpur	IRRI

Table 1: Summary of the Sampling Cites and Rice Cultivation Practices (Source: Field Survey, 2014)

3.2. Sampling Process

Three replicate samples from top soil (0-30 cm) of submerged, moistened, and fallow stages were collected. Thereafter, samples were taken into the laboratory of Asian University for Women in Chittagong, Bangladesh. 200g of each sample were separated and stored in the refrigerator at 2^0C for the estimation of microbial biomass carbon (MBC). Another 200g of soil from each sample were air dried, crushed, sieved, and labeled in order to use in further experiments. Three replicates of each submerged, moistened, and fallow soil were tested for physical parameters of soil: electric conductivity (EC), pH, organic carbon (OC) percentage, total organic carbon (TOC), and microbial biomass carbon (MBC). Rest of the samples were sealed and stored at room temperature (25 ^{0}C) for estimation of CO_2 emission.

3.3. MC

All the soil sample replicates were tested for the MC percentage in terms of the dry weight of the samples. MC percentage was calculated by applying equation [1].

[1] MC percentage= [(wet weight - dry weight) / dry weight] x 100%

3.4. EC

Soil solutions were prepared by adding 25 ml of distilled water to 5.0 g of each soil samples (1:5 soil-water ratio). EC of each sample was measured at room temperature using a conductivity meter.

3.5. pH

In order to measure pH, 10g of soil from each sample were diluted in 20 ml of 0.01 M $CaCl_2$ solution (1:2 ratio). Thereafter, pH values of each sample were measured by a pH meter.

3.6. OC Percentage and TOC

Walkly-Black method was followed to estimate the OC percentage of the samples (Schumacher, 2002). The volumes of Ferrous Ammonium Sulfate (F.A.S) consumed for each sample during titrations were recorded and applied in the equations [2] and [3] to calculate OC percentage and TOC.

[2] %OC= [(B-S) x M of F.A.S. x 12 x 100] / (0.1x 4000)

B: ml of F.A.S. solution used to titrate blank,
S: ml of F.A.S. solution used to titrate sample
M: normality of F.A.S. =0.5

12/4000: milli-equivalent weight of carbon in 0.1 g of soil
[3] TOC = % OC x 1.3

3.7. MBC

Original soil samples, which were stored in refrigerator under 2^0C, were tested for MBC. Chloroform fumigation-extraction method was followed to determine MBC of the samples (Majumder & Kuzyakov, 2010). The OC amount was calculated by applying the volume of F.A.S. concumed in equations [4] and [5].

[4] Extracted OC (µg ml^{-1}) = (H-S)/C x M x D/A x E x 1000= X
H: hot blank
S: sample reading
M: normality of K2 Cr_2 0_7 = 0.4
C: cold Blank,
D: Volume of K_2 Cr_2 0_7 solution added to the reaction mixture = 2 ml
A: Aliquot of the extract = 8 ml
E: 3 (conversion of Cr 6+ to Cr 3+)
[5] MBC = Ec/K_{EC}
Ec = (org. C extracted from the fumigated soil- org C extracted for non-fumigated soil
K_{EC} = 0.45 for 10day incubation at 25 °C

3.8. CO_2 Emission

CO_2 emission rate is estimated fallowing Majumder & Kuzyakov (2010). 10g of replicates of submerged, moistened, and fallow soil were taken in glass reagent bottles that were already labeled. Small specimen bottles were placed in two controls and reagent bottle each containing soil samples. All the specimen bottles were filled with 3ml of 1M NaOH and tied the cap to seal the bottles. After eighth, eleventh, and fifteenth days, 1ml of NaOH from each bottle was titrated against 0.1M HCl with $BaCl_2$ and phenolphthalein to estimate the trapped CO_2 in the NaOH solution. On each titrated day, the NaOH solution was replaced with new NaOH solution for the next titration. Thereafter, CO_2 emission rate was computed.

4. Results and Discussion

4.1. MC Percentage

Amongst all three rice cultivation stages, submerged soil had the highest MC percentage because rice requires high amount of water during the early stages of the growth cycle. Even though the submerged soil was flooded with water, its moisture content was about 70 percent as the rice field had loam to clay loam (Hasan, 2010). Moreover, MC of moistened soil was lower than submerged soil as the reproductive phase and the first half of the maturity phase needed an adequate water supply. Thus, the MC of moistened soil was found 40 percent, which was comparatively high. Compared to submerged and moistened soil, fallow soil had the least amount of MC percentage as the rice fields were dry due to the least water supply during the second half of maturity phase and absence of water supply after harvesting until the next land preparation took place. (Integrated Rice Management in Inland Valleys of Sub-Saharan Africa-Technical Manual, 2009).

Sample	MC Percentage	pH	EC (dS/m)
Submerged soil	68.119	5.55	0.623
Moistened soil	40.903	5.51	0.204
Fallow Soil	14.894	5.38	0.791

Table 2: Percent MC, Ph and EC of the Soil Samples

4.2. PH

pH is an important factor that determines microbial activities in soil (Neue, 1993). pH determines the growth, establishment, and the diversity of microorganisms in soil. Microorganisms such as cynobacteria and algae, which live in the soil of rice fields, prefer neutral to slightly alkaline pH conditions (Nayak & Prasanna, 2007). pH value lower than five and higher than eight are unfavorable for microbial survival because these pH ranges create stress in the environment for soil microorganisms. Thus, the organic matter degradation and decomposition will have negative impacts when acidic or alkaline conditions present in the soil of rice fields. The pH range found in the samples was 5.38 to 5.55 (Table 2), which was appropriate for rice growth and suitable for soil microorganisms to carry out decomposition (McCall, 1980).

4.3. EC

Electric conductivity has a strong co-relation with MC (Ezrin et al., 2010). EC was intermediate in submerged soil as ions are dissolved and diluted in soil solution (Table 2). Fallow soil had the highest EC because moisture of the soil had been evaporated and the ions were concentrated in dry soil. Moistened soil had the lowest EC due to two reasons. Firstly, excess water in the field, in which ions were dissolved in, was drained out of the field time to time during moistened period. Secondly, the remaining ions in the soil were homogeneously spread over the field due to water management practices.

4.4. OC percentage and TOC

After harvesting, crop residues are returned to the soil, while rice shoots are left over in the land (Majumder & Kuzyakov, 2010). During land preparation, rice field is puddle with crop residue and rice shoots to increase the organic matter (Sanders, 2000). Soil microorganisms decompose this organic matter and add most of it to the labile carbon pool and the rest to the soil carbon stock (Majumder & Kuzyakov, 2010).

Sample	OC percentage	TOC
Submerged soil	0.955	1.2415
Moistened soil	0.645	0.8385
Fallow	1.046	1.36

Table 3: OC Percentage and TOC of Submerged, Moistened, and Fallow Soil

Fallow samples were collected instantly after harvesting, after which soil was fed with crop residue and rice plant shoots. Thus, crop residue and plant shoots were not given enough time to be degraded and decomposed. Therefore, fallow soil had the highest level of OC percentage and TOC (Table 3). On the other hand, moistened soil had lower OC percentage and TOC than submerged soil because soil organic matter in moistened soil was decomposed at a higher rate compared to submerged soil due to high microbial functions (Ponnamperuma, 1972). Most soil bacteria carry out their functions actively at average moisture content, whereas microbial populations shift from aerobic conditions to facultative anaerobic conditions at high moisture soil (Herron et al., 2009). Facultative anaerobes are less efficient than aerobic microbial growth; as a result, they decrease the decomposition of OC (Herron et al., 2009). In addition, as the oxidation of organic matter is slow in submerged soil, organic matter accumulates in the top layer of soil; therefore, the OC percentage was higher in submerged soil than moistened soil (Ponnamperuma, 1972).

4.5. MBC

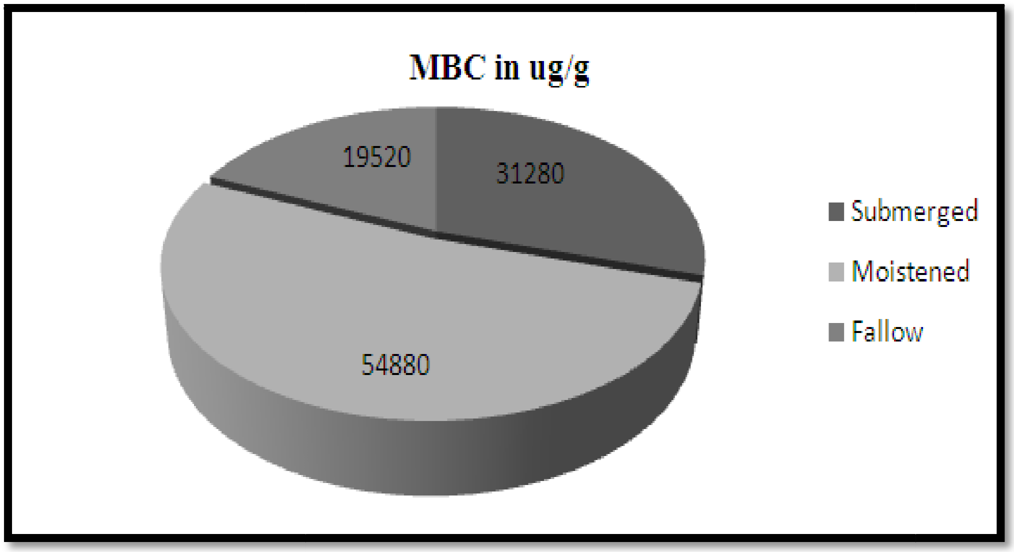

Figure 2: MBC of Submerged, Moistened, and Fallow Soil in µg/G

MC of soil highly influences the microbial growth and function, decomposition of OC, and CO_2 emission (Herron et al., 2009). Low moisture conditions cause dehydration of soil microorganisms. At the same time, moisture stress in soil reduces enzyme hydration of microbes that inhibit enzyme activities (Stark & Firestone, 1995). Also, the substrate availability for microbes becomes lower in dry soil. As a result, fallow soil had the least MBC. Therefore, fallow soil was least favorable for microbes as its MC was the lowest amongst all three samples.

Proliferation and the function of microorganisms are highest at 20-60 per cent moisture content; therefore, moistened soil had the highest MBC (My Agriculture info, 2011). At high MC, less efficient, anaerobic microorganism populations dominate the soil environment (Herron et al., 2009). Moreover, high MC favored microbial populations like methanogenic and methanotrophic microbes (Neue, 1993); hence, its MBC is higher than the MBC of fallow and lower then MBC of moistened soil.

4.6. CO_2 Emission Rate

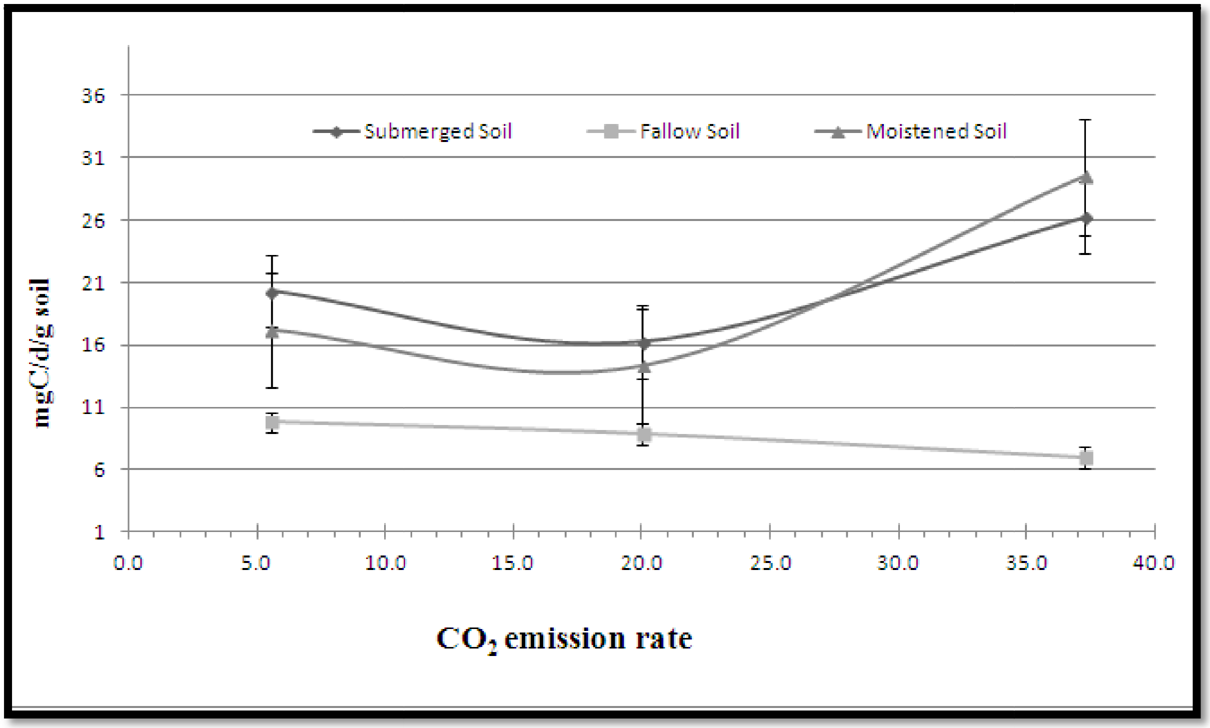

Figure 3: CO_2 Emission Rate of Submerged, Moistened, and Fallow Soil

High CO2 emission occurred from submerged soil due to catabolism of microorganisms, which was similar to alcohol fermentation (Greenway et al., 2006). When gas exchange of top soil is blocked by the water layer, soil microbes consume oxygen rapidly causing oxygen depletion (Ponnamperuma, 1972). This leads to anaerobic fermentation in the submerged soil by methanogenic microbes in the soil resulting CO_2 and CH_4 as end products (Neue, 1993). These methanogenic microbes produce methane exclusively only when there is complete depletion of oxygen. In this case, pH was a driving factor, which determined if CO_2 or CH_4 is favored during submergence because most methane producing microbes favor pH 6-8 (Neue, 1993). Since the submerged soil had pH 5.5, which was lower than pH 6, it can be concluded that the submerged soil favored CO_2 emission over CH_4 emission. Even if CH_4 was produced by methanotrophic microbes, it was oxidized into CO_2 in the presence of O_2 as the samples were exposed to the atmosphere (Institute of Biochemistry & Pollutant Dynamics, 2014). Perhaps, CO_2 emission was highest in submerge soil due to high OC readily available due to land preparation. In addition, the water layer on top of the submerged soil sample was thinner, which allowed the produced CO_2 to escape out of the soil solution easily (Greenway et al., 2006). Even though moistened soil had the highest MBC due to average moisture condition, its CO_2 was lower than the submerged soil. This could be due to the lower OC content found in moistened soil because microbes need OC to produce CO_2. Finally, the fallow soil possesses the lowest CO_2 emission due to minimum microbial activities even though it had the highest OC.

Until the second titration of the experiment, CO_2 emission of all the samples decreased. This may be due to impacts of the experimental conditions on the soil microorganisms. However, after 28th day of the experiment, CO_2 emission of submerged and moistened soil increased due to evaporation of the moisture and exchange of gases as the containers were opened. Also, the soil microbes might have adapted to the experimental conditions by this time. Hence, it became more favorable for microbial Function. However, CO_2 emission of submerged became lower than moistened soil as there was no addition of OC or nutrients; rather depletion of OC in submerged soil was at faster rate.

5. Conclusion

Even though the highest CO_2 emission was expected from moistened soil, CO_2 emission was well supported by submerged conditions; hence, CO_2 emission was highest in submerged soil. Dry conditions of rice fields caused the lowest CO_2 emission. However, it is rather difficult to maintain dry conditions in rice fields as rice plants need a considerable amount of water to complete the life cycle. Thus, intermittent irrigation techniques could be a better approach to minimize the water consumption during the vegetative and reproductive phases of the growth cycle of rice. This technique reduces the water consumption of rice fields significantly yet increases the productivity. Since this study suggests that there is a direct co-relation between MC and CO_2 emission, CO_2 emission rate could be reduced by following suggested intermittent or any suitable agricultural techniques.

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