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Changes in organic carbon pool in a tropical soil planted to rice in relation to photosynthetic carbon fixation

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Abstract

Information on the fate of photosynthesized carbon (C) in plant soil system is essential for understanding the soil organic carbon pool and carbon dynamics in agricultural ecosystem. Our objectives in the present study were to quantify the photosynthetic carbon fixation by high yielding rice genotypes and contribution of rice ecosystem to soil organic carbon pool in a tropical rice soil. A field experiment was conducted during 3 consecutive monsoon rice season (July – December) of 2012, 2013 and 2014 in a randomized block design (RBD). A portable photosynthesis system was used for measurement of flag leaf photosynthesis. Stomatal frequency of the flag leaves were studied by scanning electron microscopy (SEM). Soil organic carbon storage was estimated by a total organic carbon (TOC) analyzer. Differences in flag leaf photosynthetic carbon fixation amongst the varieties were significant. Differential ability for carbon partitioning in terms of biomass accumulation were also noteworthy ($p = 0.000$). Flag leaf photosynthetic rate observed in the study showed a good correlation ($r = 0.486$, $p \leq 0.05$) with the stomatal frequency of the flag leaves. The leaf stomatal frequency ranged from 605 to 783 mm^{-2} of leaf area with a high in the rice variety, Swarnamahsuri and low in Gitesh. There were significant differences in cumulative methane (CH_4) emission amongst the four rice varieties. The grain productivity in retaliation to genetic differences of the rice varieties highly favored their correlations with flag leaf photosynthesis ($r = 0.999$, $p \leq 0.01$) and leaf area index ($r = 0.961$, $p \leq 0.01$). Above ground and below ground dry matter of the plants were found to influence the quantity of soil organic carbon and soil C storage. Our results also clearly bespoke that a rice ecosystem can effectively sequester carbon (0.338 Mg C ha^{-1} yr^{-1}) at 0 - 15cm depth of soil. The results led us to conclude that lowland rice ecosystem is a good sink of carbon dioxide (CO_2).

Keywords: Carbon stock, dry matter partitioning, methane, photosynthesis, rice varieties, stomata.
Abbreviations: C_Carbon**;** CH_4_Methane; CO_2 _Carbon dioxide; IPCC_Intergovernmental Panel on Climate Change; GHG_ Greenhouse gas; SOM_Soil organic matter; SOC_Soil organic carbon; HAC_Humic acid carbon; FAC_Fulvic acid carbon; DOH_ Degree of humification; LAI_Leaf area index; FID_ Flame ionization detector; GC_ Gas chromatograph; TOC_Total organic carbon; SSP_Single super phosphate; MOP_Muriate of potash; RBD_Randomized block design; DAT_Days after transplanting.

Introduction

Climate change is one of the most important global environmental challenges in the history of mankind, caused by increasing concentration of greenhouse gases (GHGs) in the atmosphere. It is estimated that around 10 billion tons of carbon (C) released as CO_2 every year into the atmosphere due to human activities and less than half of this amount remains in the atmosphere, causing rise in atmospheric CO_2 concentrations (Raupach, 2011). Currently, the CO_2 concentration is reported to be 390.5 ± 0.3ppm compared to pre-industrial concentration of 278 ± 2ppm (IPCC, 2013). A net transfer of C from atmospheric CO_2 to soil and vegetation, termed C sequestration is considered a viable option for mitigating climate change (Powlson et al., 2012). Agricultural ecosystem plays a major role in mitigating the increased atmospheric CO_2 concentration because they cover a large area and function as a sink of CO_2 during the crop growth period (Lal, 2004). Rice–wheat cropping system has higher potential for C sequestration relative to other tropical ecosystems and more efficient in partitioning of biomass C compared to legumes and other crops (Kukal et al., 2009). Crop species play an important role in maintaining quantity and quality of SOC stock despite diverse nature of crop residues with highly variable turnover or residence time in the soil (Benbi et al., 2012). The adaptive potential of photosynthesis to changing environments depends on the level of genetic variation for photosynthesis in diverse rice genotypes. As plant biomass is largely derived from photosynthetically captured carbon, variation in the efficiency or capacity of photosynthesis can lead to variation in growth rate and productivity. Plant roots play a dominant role in the soil C cycle and greatly influence the SOC stock than the above ground biomass (Puget and Drinkwater, 2001) through root exudates, mucilages, sloughed off root cap cells and senescence of older roots contributing to rhizodeposition in the soil (Saikia et al., 2015). Productivity of crop plants depends on the efficiency of photosynthesis, translocation of assimilates and formation of active sinks, where leaf canopy plays a determining role influencing source-sink relations (Iqbal et al., 2012). Carbon dynamics of agro ecosystem is difficult to quantify on a larger scale due to spatial and temporal variations in climate, soils and agricultural practices (Hollinger et al., 2005). Plant fixes atmospheric CO_2 by photosynthesis in the leaves and later the C is released through the root system and deposited in the soil. C in soil organic matter (SOM) is contained in humic and non-humic substances; thus carbon stability is related to the degree of humification (DOH) of SOM. Humic acid carbon (HAC) and fulvic acid carbon (FAC) are highly humified SOM fractions and are more stable compared to less humified ones (Ferreira et al., 2014). This study focuses on role of rice ecosystem on soil C storage after cultivation for several successive years. The present study was conducted with the following objectives (1) to quantify the photosynthetic C fixation efficiency in a rice ecosystem by different rice varieties, (2) amount of C partitioned to different plant parts of the rice crop, (3) to investigate the impacts of different rice varieties in an ecosystem on soil carbon storage in rice fields.

Results

Genotypic differences of rice varieties in flag leaf photosynthesis, plant biomass accumulation, LAI, grain yield and yield attributes at harvest

Flag leaf photosynthesis of the varieties were considerably lower during initial development of the flag leaves, reached a high peak at 105 DAT and slightly declined thereafter (Fig. 1). The significant reduction in the rate of photosynthetic carbon fixation was observed in the varieties Ranjit and Gitesh at 91 DAT. Statistical analyses showed that the effect of year, the effect of a variety and variety vs. year on flag leaf photosynthetic rate was significant. The varieties exhibited marked differences in the photosynthetic rate of the varieties ($p = 0.000$) irrespective of the date of sampling. The variety Swarnamahsuri recorded higher flag leaf photosynthetic rate during 98, 105 and 112 DAT, relative to the rates of other varieties.

Increment in the plant root and shoot biomass of the varieties was highest at the flowering stage and least at the tillering stage of the crop growth (Table 1). The differences in the increment of root and shoot biomass accumulation among the varieties was notable over the three seasons of study. However, statistical analyses unveiled a significant year and varieties interaction in root biomass at all the stages of growth. Similar results were also perceived in relation to shoot biomass of the varieties.

Higher LAI was recorded in Mahsuri (V4) at panicle initiation stage compared to other varieties and showed a good correlation with grain yield (Table 1 and 2). The effect of year, variety and year vs. variety were significant for plant biomass accumulation, partitioning and LAI. Among the varieties, Mahsuri recorded higher shoot biomass during the experimental period but the pooled analyses of the data revealed higher shoot biomass in variety Swarnamahsuri (Table 1).

Rice yield showed wide variations among the varieties. Statistical differences documented that there were significant effects of the number of productive tillers, filled grain (%), 1000-seed mass and high density grain on the grain yield of the varieties (Table 2). Comparable increase in the number of productive tillers, the numbers of seeds per panicle along with higher filled grain and high density grain have contributed to higher grain productivity of Swarnamahsuri (V3). Our results on grain productivity in retaliation to genetic differences of the varieties highly favored their correlations with flag leaf photosynthesis ($r = 0.999$, $p \leq 0.01$) and LAI ($r = 0.961$, $p \leq 0.05$). The grain yield of the rice varieties in the ecosystem followed an order of Swarnamahsuri (51.46 Q ha^{-1}) followed by Mahsuri (48.78 Q ha^{-1}), Ranjit (45.15 Q ha^{-1}) and Gitesh (25.57 Q ha^{-1}).

Variation in leaf stomatal metrics among the rice varieties

Stomatal frequency were analysed in flag leaves of the varieties at panicle initiation stage (Fig. 2). Stomatal frequency showed a good correlation ($r = 0.486$, $p \leq 0.05$) with the photosynthesis of the flag leaves, with a high in Swarnamahsuri (783) followed by Ranjit (687), Mahsuri (625) and Gitesh (607) mm^{-2} of leaf area at the adaxial surface of the leaves. Results of stomatal frequencies in our study revealed a wide variation among the varieties and were statistically significant.

Changes in soil organic carbon, humic and fulvic carbon fractions

Compared to the base value (1.08 %), SOC content increased at 0 - 15cm soil depth during all the 03 seasons of study. After 03 years of cropping, we observed higher SOC (%) in the panicle initiation stage of the crop. SOC (%) was significantly influenced by the varieties at the 0 - 15cm (Fig. 3a). Initial declines in the SOC content were also observed in the tillering stage of the crop. SOC content showed a trend of consistent increase upto the panicle initiation stage, and gradually declined thereafter till harvest. The magnitude of SOC (%) in the field with different varieties at the upper soil layer followed an order of Swarnamahsuri > Ranjit > Mahsuri > Gitesh. Higher SOC storage was observed at panicle initiation stage irrespective of the varieties with a high SOC in field grown with variety Swarnamahsuri (V3) and a low in Gitesh (V2). At the 0 - 15cm soil layer, SOC stock calculated at 4 different plots grown with 4 different varieties did not reveal any statistical difference at panicle initiation stage of the crop (Fig 3b). However, varieties depicted a significant role on SOC storage at tillering, flowering and maturity stages. However, an apparent increment in the SOC stock in the rice field soil was observed after 3 years of study in a monsoon rice ecosystem. The SOC stock in the field grown with the 4 varieties at 0 - 15cm soil layer at harvest of the crop was in the order of 19.07 (Ranjit) > 18.06 (Gitesh) > 18.02 (Swarnamahsuri) > 16.03 (Mahsuri) Mg C ha^{-1}. Throughout the crop growth period, SOC stock at 0 - 15cm was highest during panicle initiation stage in the field grown with the variety Swarnamahsuri (25.05 Mg C ha^{-1}) and least at Mahsuri grown plots (16.30 Mg C ha^{-1}) at harvest (Fig 3b). We analyzed the humic substances in the 0 - 15cm soil layer at harvest of the crop to analyze the stability of soil C after 3 years of study. The fulvic acid carbon (FAC) and humic acid carbon (HAC) after three consecutive years of study were 0.039%, 0.039%, 0.135%, 0.096 % and 0.454%, 0.405%, 0.531%, 0.438% in the field grown with the varieties Ranjit, Gitesh, Swarnamahsuri, Mahsuri respectively. Similarly, degree of humification (DOH) follows the order of 2.71 (Swarnamahsuri) > 2.64 (Ranjit) > 2.63 (Mahsuri) > 1.93 (Gitesh). The fields planted with different varieties showed a difference in trend of the humic substances. The variety Swarnamahsuri (V3) planted field recorded higher FAC, HAC and DOH compared to the fields with other varieties (Fig. 4). While comparing the base value, an increment of 6.03% increase in C was recorded at the 0 - 15cm by the monsoon rice ecosystem after 03 years of study. The amount of carbon remained and stabilized in the entire profile (0 - 15cm) after 3 years of study was estimated to be:

= SOC (after 3 years) - SOC (initial)

= 17.863 – 16.848

=1.015 Mg C ha^{-1}

i.e 0.338 Mg C ha^{-1} yr^{-1} in the soil.

Effects of rice varieties on methane emission and soil carbon dioxide efflux

Fluxes and pool sizes of CH_4 during the growing season of the rice crop was initially low but increased with the crop growth up to panicle initiation stage and emission started to decline thereafter. Measurements of CH_4 fluxes from the rice varieties indicated significant varietal differences in CH_4 emission. The CH_4 emission during the crop growing season varied from 0.082 - 0.767 mg m^{-2} hr^{-1} (Fig. 5a). Two high peaks, one at tillering stage (49 DAT) of the crop and the other at panicle initiation stage (77 DAT) were perceived irrespective of the varieties although there were wide variations in emission of CH_4 amongst the varieties and a low peak was observed at harvest (126 DAT) of the crop. Highest cumulative methane emission was recorded from the variety Mahsuri and lowest from Gitesh (Fig 5b) and differences in cumulative CH_4 emission amongst the varieties were prominent. The cumulative CH_4 flux values were 14.2 kg ha^{-1} in V4 (Mahsuri), 13.5 kg ha^{-1} in V3 (Swarnamahsuri), 12.6 kg ha^{-1} in V1 (Ranjit) and 10.8 kgha^{-1} in V2 (Gitesh). Organic carbon at the upper depth of soil revealed a good correlation with methane emissions ($r = 0.833$, $p \leq 0.01$) in our study.

Fluctuations in soil CO_2 efflux were observed at different growth stages of the crop and high efflux (soil respiration) was recorded at panicle initiation stage and at harvest (Fig. 6). Soil respiration was relatively low during the tillering stage. High soil respiration was documented at Swarnamahsuri and Mahsuri grown plots followed by Ranjit and Gitesh during the panicle initiation and harvest.

Discussion

Decline in photosynthesis rate observed at 91 DAT in the varieties Ranjit (V1) and Gitesh (V2) was due to reduction in the light intensity inside the canopy. The observed differences in the relationship of gas exchange parameters are attributed to genotypes and are in good agreement with findings of Hirasawa et al., (2010) which highlights the genotypic differences in photosynthetic rate of flag leaves. Flag leaf photosynthesis revealed a good correlation with root biomass of the varieties. Increased uptake of atmospheric carbon by the cultivar Swarnamahsuri accompanied by higher root biomass may be the reason for higher soil organic carbon in Swarnamahsuri planted field by following a mechanism of carbon release from the roots to the soil reported by Kuzyakov and Gavrichkova, 2010; Saikia et al., 2015. The enhanced photosynthetic rate has resulted in profuse vegetative growth and is the cause of higher dry matter partitioning to the root and the shoot of the cultivars. Our results are in agreement with the findings of Makino, 2011, where more than 90% of crop biomass is reported to be derived from the photosynthetic products. A correlation of flag leaf photosynthesis with yield is clear in our study which helps us to conclude that higher rate of photosynthesis during the reproductive growth phase followed by efficient dry matter partitioning to grain have contributed to higher grain productivity in the variety Swarnamahsuri. The flag leaf usually contributes most of the photosynthates to the grain (Inoue et al., 2004) and differences in flag leaf photosynthesis may be one of the reasons of differential grain productivity in the varieties (Table 2). The proportion of photosynthates partitioned to roots depends mainly on plant genetic and edaphic factors (Munoz-Romero et al., 2010). These results allowed us to explain that the variety, Swarnamahsuri because of its superior genetic traits recorded high photosynthetic rate and efficient partitioning of biomass to roots and are the possible but not conclusive reason of higher carbon enrichment of the soil (Table 1). Studies conducted using tracer methods indicate that for cereals, about 20 –30 % of assimilated C is translocated below ground (Kuzyakov and Domanski, 2000), and supports our findings of root derived C enrichment of soil. In the present study, leaf biomass accumulation showed parallel effect on LAI (Table 1). Light harvesting capability of different rice varieties might be a cause of the observed differences in LAI and our results are well corroborated with the recent findings of Su et al., (2014). Higher numbers of productive tillers and filled grain (%) might have contributed to higher grain productivity of the variety Swarnamahsuri (Makino, 2011). Number of fertile tillers and LAI may be another reason for higher grain productivity in Swarnamahsuri and is in good agreement with Fageria et al., (2007). The differences in grain yield among the varieties are attributable to the differences in photosynthetic efficiency and grain filling efficiencies (Table 2).

Stomatal frequency of the flag leaf is an important determinant factor for efficient gaseous exchange from green leaves. The increased stomatal density observed in Swarnamahsuri (V3) is considered to be the reason of enhancement of leaf photosynthetic capacity of this variety by modulating uniform gas diffusion. Recently, expression of a gene called "Stomagen" is reported to be regulator of stomatal development and functioning by Tanaka et al., (2013). Differences in stomatal characteristics among the rice varieties might be because of differences in expression of "stomagen" in these varieties. Notwithstanding, the underlying mechanism, our results specify an additional benefit of increased stomatal density on photosynthesis (Leakey et al., 2009) and can be a suitable attribute to improved photosynthetic efficiency of crops. Franks and Beerling, 2009 also reported that higher frequency of stomata and stomatal conductance results in greater CO_2 fixation due to shorter path length for gas diffusion, and a similar mechanism might result in high photosynthetic efficiency of the variety Swarnamahsuri in the present study.

Greater portion of the roots of the rice varieties were found to be within 0-15cm depth and might have contributed to higher soil organic carbon in the top layer of soil and is in concordance with Ghimire et al., (2012). Lower soil organic carbon recorded at the initial stage of the crop growth is considered to be due to less decomposable organic matter in soil (Baruah et al., 2010), which started to increase till flowering stage of the crop and gradually downswing thereafter. Higher organic carbon in soil at these stages are accredited to higher above ground biomass in rice and the results are in conformity with the findings of Kukal et al., 2009, Benbi et al., 2012. Further, rice crop is reported to enrich the soil with organic carbon through root exudation, sloughed off root cap cells depending on the biomass quantity of roots (Balasooriya et al., 2014) and this also lent support to our findings. Higher root biomass of the variety Swarnamahsuri has contributed to higher SOC in our study (Table 1). The bulk density of the soil was found to be negatively correlated with soil organic carbon and similar findings are reported by Goidts, (2007). Bulk density was lower in the upper layer 0 - 15 cm of soil than in the bottom layer might be due to root biomass accumulation, as reported by Throop et al., (2012). Higher root biomass and root

Table 1. Leaf Area Index (LAI) at PI stage and plant dry matter partitioning (g $hill^{-1}$) of the varieties during 4 growth stages (values are pool analysis of 3 years). TL – Tillering, PI – Panicle Initiation, FL – 50% Flowering, H – Harvest. Values (mean ± standard error) followed by same letters are not significantly different from each other in the same column at P ≤ 0.05 according to Duncan's Multiple range test. Y - Years, V – Varieties, LSD – Least Significant Differences

	LAI	Root (TL)	Shoot (TL)	Root (PI)	Shoot (PI)	Root (FL)	Shoot (FL)	Root (H)	Shoot (H)
Ranjit	3.50 ± 0.11c	1.68 ± 0.12a	6.09 ± 0.51c	3.95 ± 0.65b	17.62 ± 2.36d	8.33 ± 1.79b	44.28 ± 1.77b	8.27 ± 1.81b	39.03 ± 2.36b
Gitesh	2.00 ± 0.03d	1.45 ± 0.10b	6.84 ± 0.42b	3.22 ± 0.36c	20.44 ± 1.06b	6.32 ± 1.00d	33.75 ± 2.22d	6.09 ± 1.12c	31.60 ± 2.06c
Swarnamahsuri	3.74 ± 0.20b	1.31 ± 0.06b	6.18 ± 0.84c	4.56 ± 0.76a	18.54 ± 2.29c	10.72 ± 1.9a	47.81 ± 2.79a	9.37 ± 2.11a	42.29 ± 4.09a
Mahsuri	3.92 ± 0.24a	1.83 ± 0.14a	9.02 ± 0.72a	4.65 ± 0.93a	24.27 ± 3.27a	7.54 ± 1.18c	41.87 ± 1.37c	6.48 ± 1.32c	36.71 ± 0.56b
Y (p values)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y × V	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LSD (V)	0.032	0.091	0.258	0.283	0.290	0.173	0.373	0.347	1.390

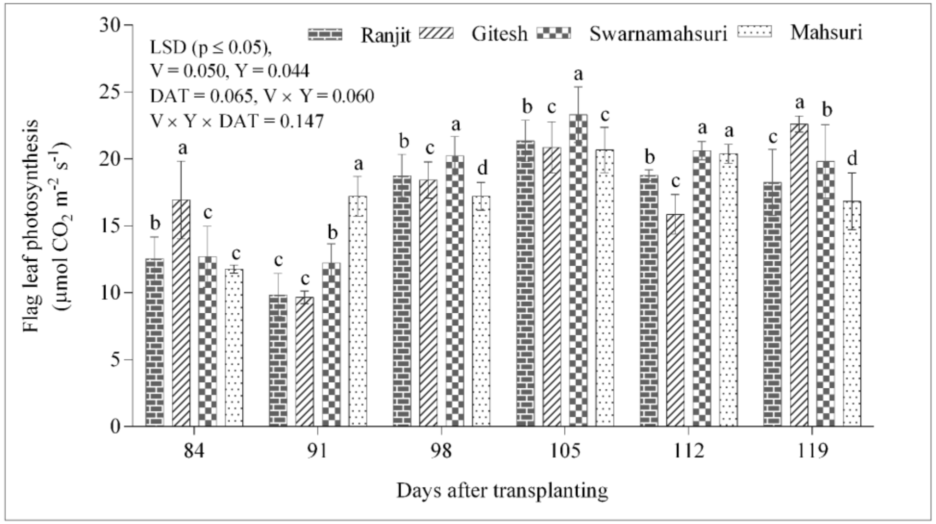

Fig 1. Changes in flag leaf photosynthesis (μmol CO_2 m^{-2} s^{-1}) of the rice varieties. Values (mean ± standard error) followed by same letters are not significantly different from each other in the same column at p ≤ 0.05 according to Duncan's Multiple range test.

Table 2. Yield and yield attributing parameters of the varieties at harvest (values are pool analysis of 3 years). Values (mean ± standard error) followed by same letters are not significantly different from each other in the same column at P ≤ 0.05 according to Duncan's Multiple range test. Y- Years, V – Varieties, LSD – Least Significant Differences

	Fertile tiller m^{-2}	Unfertile tiller m^{-2}	Panicle length (cm)	Grains $panicle^{-1}$	Filled grains (%)	1000 grain weight (g)	High density grain (%)	Harvest index	Grain yield (Q ha^{-1})
Ranjit	352 ± 15c	23 ± 3b	21.53 ± 0.36b	156 ± 6b	87.15 ± 2.64b	18.89 ± 0.70b	77.91 ± 1.84b	29 ± 3.34b	45.15 ± 2.38c
Gitesh	291 ± 12d	31 ± 3a	19.66 ± 0.45c	101 ± 2c	86.67 ± 2.08b	18.06 ± 0.75c	75.21 ± 3.62c	25 ± 3.90c	25.57 ± 1.75d
Swarnamahsuri	381 ± 15a	17 ± 2c	21.44 ± 0.36b	169 ± 4a	89.01 ± 2.15a	19.93 ± 0.58a	81.06 ± 2.56a	39 ± 4.65a	51.46 ± 1.98a
Mahsuri	363 ± 16b	19 ± 2c	23.12 ± 0.41a	170 ± 3a	87.11 ± 2.24b	19.98 ± 0.55a	79.86 ± 2.93a	32 ± 4.01b	48.78 ± 2.27b
Y (p values)	0.000	0.000	0.073	0.000	0.000	0.000	0.000	0.000	0.000
V	0.000	0.000	0.000	0.000	0.041	0.000	0.000	0.000	0.000
Y × V	0.000	0.001	0.057	0.006	0.001	0.027	0.000	0.089	0.000
LSD (V)	5.848	1.409	0.469	3.844	0.822	0.275	0.836	1.731	1.409

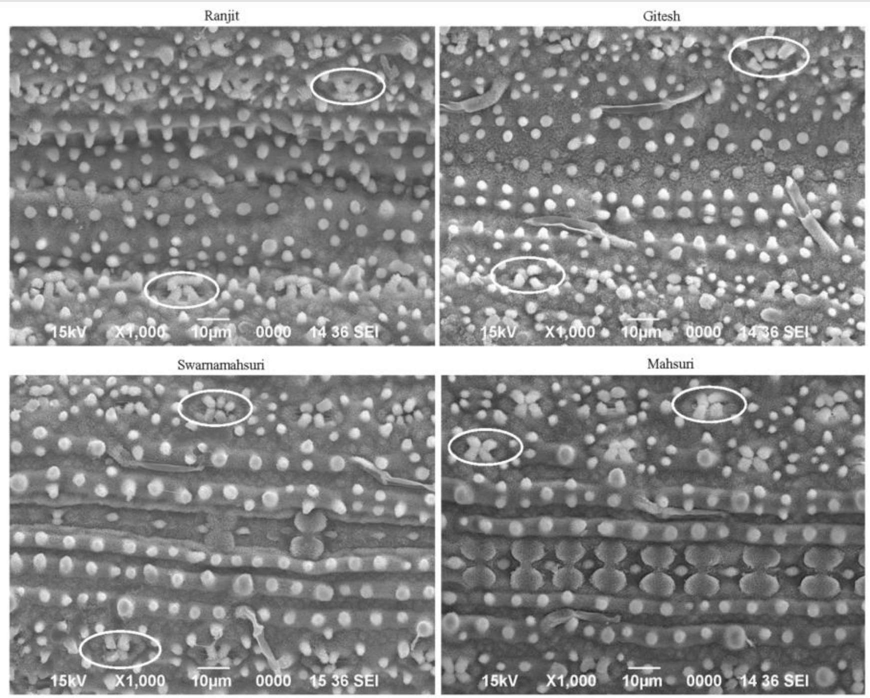

Fig 2. Scanning electron micrographs of stomata on the adaxial leaf surfaces of the rice varieties of Ranjit, Gitesh, Swarnamahsuri and Mahsuri at panicle initiation stage. Circled areas in the micrographs indicate the individual stomata.

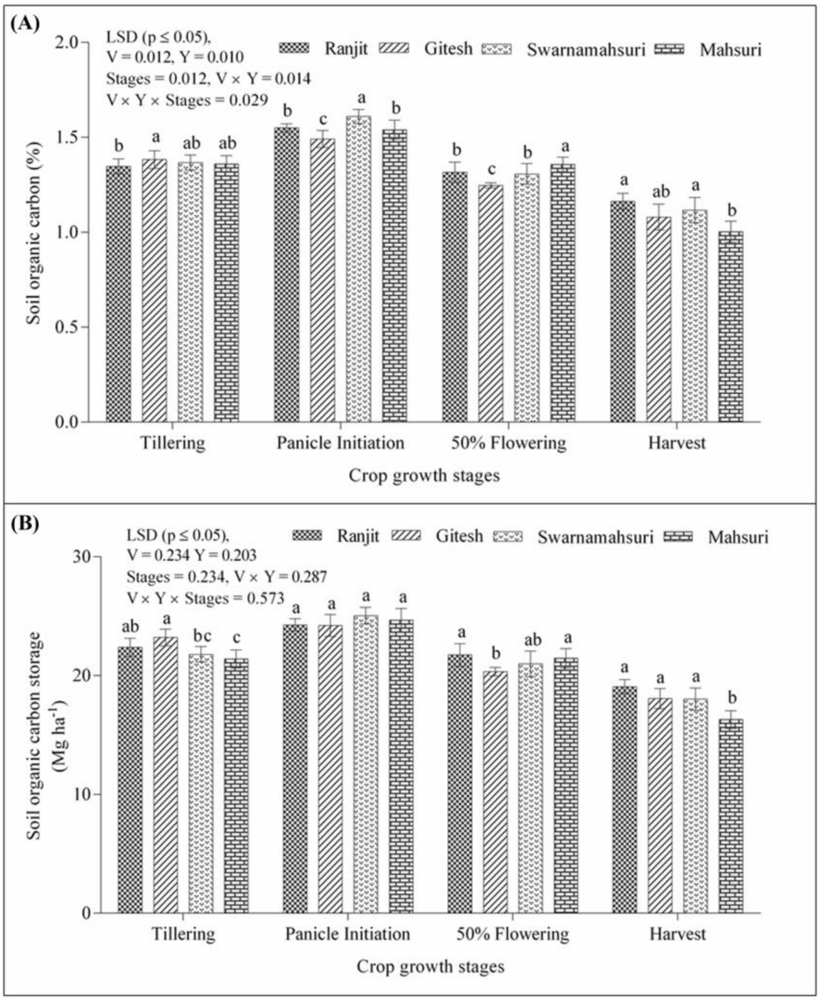

Fig 3. Changes in organic carbon at 0 - 15cm depth of soil at 4 growth stages viz. tillering, panicle initiation, 50% flowering and at harvest, (A) soil organic carbon (%) and (B) soil organic carbon storage (Mg C ha^{-1}). Values (mean ± standard error) followed by same letters are not significantly different from each other in the same column at p ≤ 0.05 according to Duncan's Multiple range test.

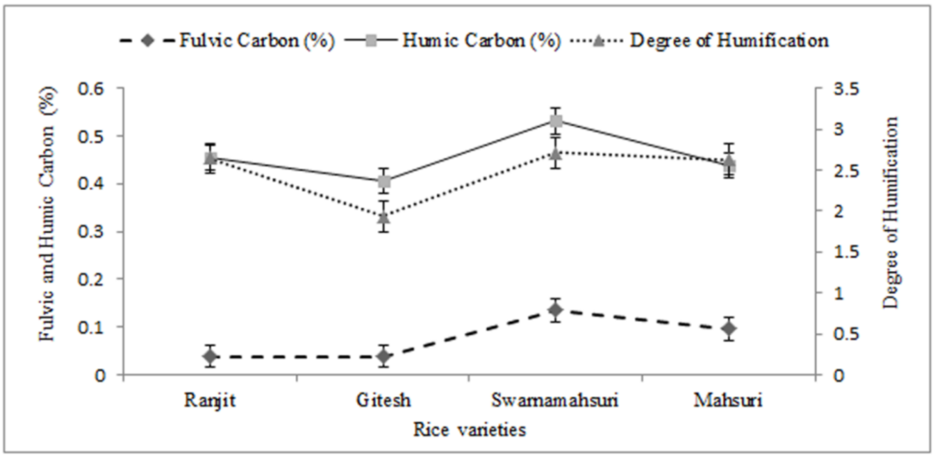

Fig 4. Fulvic carbon, humic carbon and degree of humification recorded from the field grown with the different varieties at harvest of the crop (after 3 years of study). Values represent mean ± standard error.

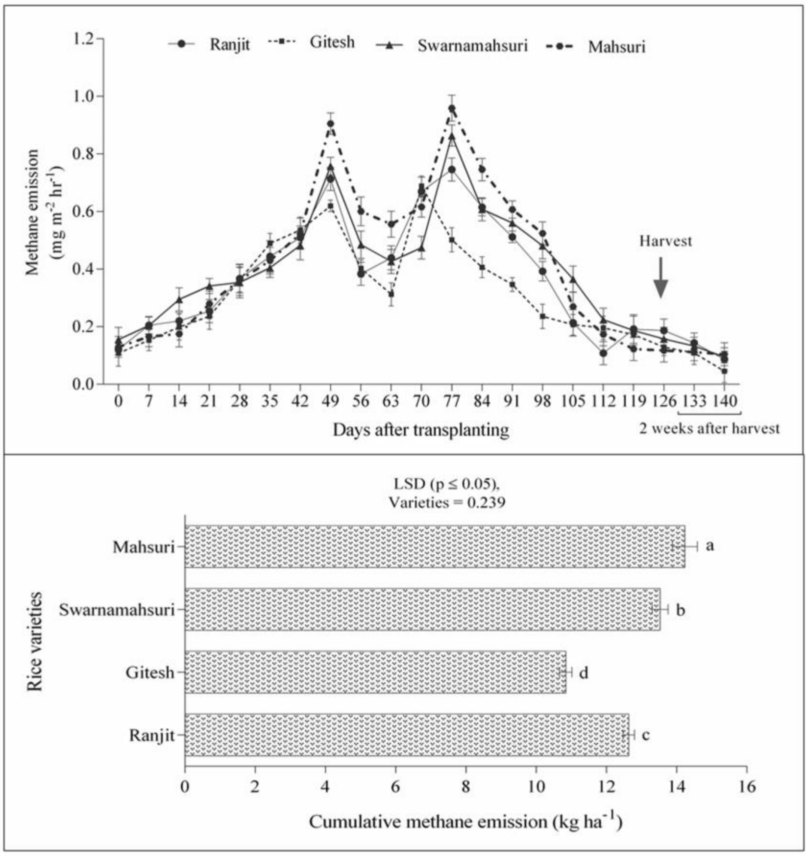

Fig 5. Methane (CH_4) emission during the crop growth period (A) Fluxes of CH_4 emission (mg m^{-2} hr^{-1}), (B) Cumulative CH_4 emission (kg ha^{-1}). Values (mean ± standard error) followed by same letters are not significantly different from each other in the same column at $p \leq 0.05$ according to Duncan's multiple range test.

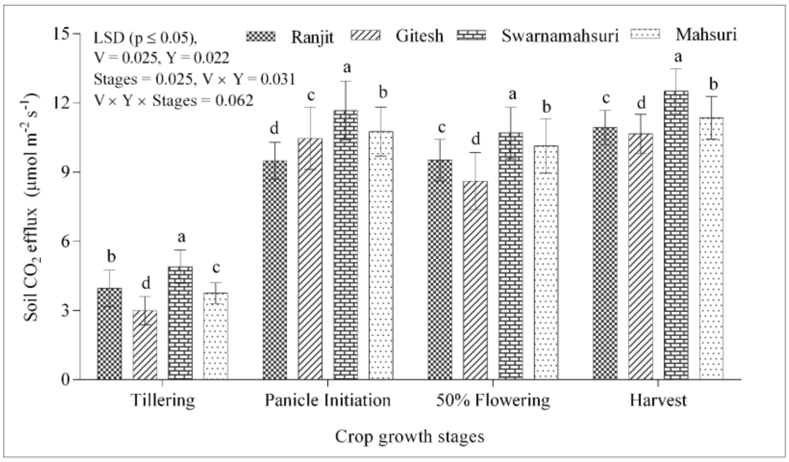

Fig 6. Soil carbon dioxide efflux (µmol m^{-2} s^{-1}) at 4 growth stages of the rice varieties. Values (mean ± standard error) followed by same letters are not significantly different from each other in the same column at $p \leq 0.05$ according to Duncan's multiple range test.

distribution at 0 - 15cm depth observed in the present study have contributed to lower bulk density at this depth and our results are in agreement with Goidts, (2007). The observed variation in soil organic carbon (%) and SOC storage in the field planted with different rice varieties may be due to their genotypic differences for root biomass accumulation and subsequent release of carbon into the soil. In agro ecosystems, carbon inputs from plants into the soil are reported to increase through plant roots, root and shoot residues contributing to rhizodeposition (Ghosh et al., 2012; Chirinda et al., 2012). We also report here that higher biomass of a variety in rice ecosystem enriches the soil with C and is the cause of efficient C storage.

The carbon balance of an ecosystem is depended on two components i.e the addition of C (C influx) to the rice system and removal of C (C efflux), and hence we focus on the C efflux by estimating CH_4 emission and CO_2 efflux from soil. Two high peaks of CH_4 observed at active vegetative stage of the crop and at reproductive stage, irrespective of the cultivars (Fig 5a) is in consistency with the available literature on rice (Das and Baruah, 2008a,b; Zheng et al., 2011). Increased gas transport and larger canopy in terms of shoot biomass and leaf area might have contributed to higher methane emissions from high emitting variety like Mahsuri. The strong relationship observed between SOC and CH_4 emission in the present study is attributed to greater availability of substrates in the rhizosphere which provided carbon sources for methane production through methanogenesis. The lower carbon storage observed in the field planted with the variety Mahsuri might be due to higher carbon loss in the form of CH_4.

Rice crop tends to exchange most of the C as CO_2 to the atmosphere. In the topsoil horizon, the amount of CO_2 produced through root-related respiration depends on size of the root system, autotrophic respiration rates (i.e. respiration per unit of root biomass), root turnover, and decay (Luo and Zhou, 2006). In this study, root biomass has positively influenced soil carbon dioxide efflux. The C flux between SOC pools and the atmosphere depends on biomass production, organic mattter input and soil respiration (Valentini et al., 2000). Root biomass of the variety Swarnamahsuri and decomposition of root exudates might have resulted in higher soil respiration from the field planted with Swarnamahsuri. Decomposition of root exudates is also reported to produce stable humified organic substances (Bhattacharyya et al., 2010) and can be a cause of higher soil respiration. These results allowed us to assume that SOC storage in the fields planted with Swarnamahsuri might be the result of humified substances. Maximum increment in FAC and HAC was recorded in the fields planted with Swarnamahsuri after 3 years of study. This indicate stabilization of the soil and formation of persistent organic C in the form of humified organic carbon (fulvic acid carbon and humic acid carbon) (Zhou et al., 2014), which leads to more carbon sequestration potential of a soil. Similarly, DOH used to express the ratio of aromatic and aliphatic C content was higher in the plots grown with the variety Swarnamahsuri due to more stable carbon fractions such as FAC and HAC. Several reports on soil carbon dynamics have focused that soil CO_2 emissions from rice are relatively small and rice soils act as a C sink. Our results on the relationship of soil CO_2 efflux and carbon storage 1.015 Mg C ha^{-1} after 3 years of monsoon *(Sali)* rice cultivation are in agreement with McMillan et al., (2007), Bhattacharya et al., (2014).

Materials and Methods

Site description

A field experiment was conducted inside Tezpur Central University campus (26˚- 41´ N, 92˚- 50´ E, 48m above sea level) in the state of Assam, India during monsoon rice growing season (July - December) of 2012, 2013 and 2014. The climate in the zone is humid subtropical characterized by a warm humid climate having hot summer. The experiment commenced in June, 2012 on a sandy loam soil (55.75% sand, 15.9% silt and 28.35% clay). The locus of the experimental field is the North Bank Plain Agro climatic Zone of Assam, India. The soil properties at 0 - 15cm soil layer at the onset of the experiment were: pH, 5.7; organic carbon, 1.08 %; bulk density, 1.04 Mg m^{-3}; available nitrogen, 101.15 kg ha^{-1}; available phosphorous, 32.35 kg ha^{-1}; and available potassium, 200.62 kg ha^{-1}. Precipitation and daily maximum and minimum temperature were recorded during the experimental period from the 0 (zero) DAT to 2 weeks after harvest. The total precipitation recorded during the experimental period was 544.58 mm, 510.56 mm and 274.32 mm during 2012, 2013 and 2014 respectively. The average maximum and minimum temperature during the experimental period ranged from 31.33°C to 19.60˚C in 2012 and 30.66°C to 21.34°C during 2013, 31.45°C to 22.98°C during 2014. The climate data were obtained from a weather station located at the university campus.

Experimental design, crop establishment and rice varieties

The experiment was laid out in a RBD with 5 replications for each variety. 4 high yielding rice varieties, Ranjit (V1), Gitesh (V2), Swarnamahsuri (V3) and Mahsuri (V4) were selected for these experiments. The seeds of the above varieties were sown in a well prepared seedbed during 3rd week of June each year (2012, 2013, and 2014). Main field was ploughed thoroughly and flooded for 2 - 3 days before transplanting. 20 plots of size 4m x 4m were prepared with bunds of 0.5m between each of them. Urea (N) was applied in the field as per recommendation of Assam Agricultural University, Jorhat @ 60:20:40 kg N-P_2O_5-K_2O ha^{-1}. Out of the 60kg ha^{-1} N recommended, 30kg ha^{-1} was applied as basal at the time of transplanting the crop. From the remaining 30kg, 15kg ha^{-1} was applied at tillering stage and 15kg ha^{-1} at panicle initiation stage of the crop. Entire quantity of P_2O_5 (20kg ha^{-1}) in the form of SSP and K_2O (40kg ha^{-1}) in the form of MOP along with N in the form of urea (30kg ha^{-1}) were applied at the time of final puddling. 30 - 35 days old seedlings were transplanted during fourth week of July of each experimental year. The spacing of transplantation of the seedlings in the main field between row to row and hill to hill was 20cm × 15cm with 3 seedlings assigned to each hill.

Soil, plant and methane emission measurements

The soil samples were collected from 0 - 15cm depth of soil prior to start of the experiment (before ploughing the field) during June, 2012 by a soil core sampler (7cm inner diameter and 40cm length). The soil samples were collected from various locations of the experimental area, and then three composite samples were prepared as representatives of the plot. The physico-chemical properties of the initial soil samples (soil texture, p^H, bulk density, available N, available P and available K) collected prior to the start of the experiment, were analyzed by the methods of Baruah et al., (2012). Soil samples from 0 - 15cm soil layer were collected at tillering, panicle initiation, 50 % flowering and at harvest for analyzing SOC changes during the growth period of the rice crop during 2012, 2013 and 2014. Sampling was done from five different places within individual replicated plots and these five samples were mixed together to prepare a composite sample for the plot. Immediately after sampling, visible root fragments and stones were removed manually and transferred to the laboratory. The fresh soil was air dried for 7 days, sieved through a 2mm mesh, mixed and analyzed for SOC % by a TOC Analyzer (Model: Multi N/C 2100S, with solid module HT 1300, Analytik Jena, Germany). Soil samples were analyzed for inorganic carbon by a Fizz test using dilute H Cl (Jackson, 1967). Absence of effervescence from the soil samples confirmed the absence of inorganic carbon. The SOC concentration in the soil samples was converted to mass basis using the formula of Benbi et al., (2012)

SOC (Mg ha^{-1}) = C% × bulk density (Mg m^{-3}) × depth (m) × 100

Carbon sequestration in soil by the monsoon rice ecosystem was computed as the change in SOC storage in (0 - 15cm) soil layer since the start of the experiment: C sequestered (Mg C ha^{-1} soil) = $SOC_{current} - SOC_{initial}$ where

SOC current indicates the SOC stocks of 0 - 15cm soil layer in December, 2014 (at the end of 3 years) at harvest of the crop and SOC initial indicates SOC stocks that was estimated before initiation of the experiment in June, 2012. Soil CO_2 efflux was measured by Automated CO_2 Flux system (LI - 8100A, LICOR, USA). At harvest of the crop, after 3 years of study, the soils were analyzed for HAC, FAC and DOH following the analytical procedures of Page et al., (1982).

Destructive samplings of plants were done manually for estimation of dry matter partitioning of C. The plant parts were separated into roots and shoots and then oven dried at 70°C for dry matter estimation. Leaf area index was measured by using a portable laser leaf area meter (CID model CI - 203, Camas, WA, USA). Rate of photosynthesis (μ mol CO_2 m^{-2} s^{-1}) was measured in the flag leaves at weekly interval (after panicle initiation of the crop till harvest) by an infrared gas analyzer (Model LI - 6400, portable photosynthesis system; LICOR, Lincoln, NE, USA) under ambient environmental conditions. Stomatal frequencies of the flag leaves at panicle initiation stage were done by Scanning Electron Microscopy (JEOL, JSM - 6390LV, Japan). Three random fields from each sample were taken for the measurement of stomatal frequency (from the adaxial surface of the leaf sample) and expressed as number of stomata mm^{-2} of leaf area.

CH_4 flux was measured from the rice fields at 7-day intervals from 0 days of transplanting till 2 weeks after harvest by using a static chamber technique described by Parashar et al., (1996). The detailed methodology of gas sampling was followed from Das and Baruah, (2008 a, b). The samples were brought to the laboratory from the field and CH_4 concentration was determined by a Varian (Model-3800, USA) gas chromatograph. Methane flux was calculated from the concentration of CH_4 obtained through GC analysis by the equation of Parashar et al., (1996) and Parashar and Fisher, (1998). Cumulative CH_4 emission for the entire crop growth period was computed by the following equation of Ma et al., (2009).

Cumulative CH_4 emission (gm^{-2}) = $\sum_{i=1}^{n}(Fi \times Di)$

Where F_i indicates measured flux in the i^{th} sampling interval, Di indicates the number of days and n is the number of sampling intervals and expressed as g m^{-2}. The values were converted to kg ha^{-1} by multiplying with a factor 10.

Data analysis

All statistical analyses were performed with SPSS 20.0 (SPSS, Inc., USA). The dataset for 3 consecutive years were computed for two way analysis of variance (ANOVA) with year and varieties as factors. Means for pooled significant effects were separated using Duncan's multiple range tests at 0.05 probability level considering the varieties as source of variation and their interaction with years. Correlations among the parameters were done by Pearson correlation method.

Conclusion

The study comprising of both carbon influx and carbon efflux disseminated that monsoon rice ecosystem has the capacity to store carbon in soil and can act as a net carbon sink. Our results have clearly shown differences in the root and shoot biomass among the varieties and have different ability for biomass partitioning i.e. carbohydrate. The cultivar, Swarnamahsuri with higher photosynthesis, efficient partitioning of carbon in terms of root biomass and with higher grain yield is considered a significant finding of this study. During the 3 years of this study, it is concluded that monsoon rice ecosystem can act as an effective sink of carbon with an overall SOC accumulation rate of 0.338 Mg C ha^{-1} yr^{-1} at the 0-15cm layer of soil. Thus, there exist a potential of a rice ecosystem to efficiently sequester carbon. Although the sink capacity of biotic carbon sequestration (through photosynthesis, humification etc) is finite over abiotic carbon sequestration (through engineering etc), the biotics is cost effective and environment friendly in an agriculture system. Therefore, enhancing photosynthesis either by selection of efficient genotype and/or through efficient crop management can be a suitable tool for carbon capture and carbon sequestration.

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