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EFFECT OF ALTERNATE WETTING AND DRYING VERSUS CONTINUOUS FLOODING ON CARBON RATES IN RICE AND SOIL

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Abstract

An experiment was conducted at Bangladesh Institute of Nuclear Agriculture (BINA) farm, Mymensingh, Bangladesh during 2010-2011 to find out the effect of different water and organic residue rates on rice and soil. Organic carbon rates from cow dung (0.5, 1.0, 1.5 and 2.0 t C ha^{-1} including control) were evaluated under alternate wetting and drying (AWD) and continuous flooding (CF). CF system in combination with chemical fertilizers and 2.0 t C ha^{-1} produced the maximum plant height, filled grains $tiller^{-1}$, 1000 grains weight, grain and straw yields. Combined use of 2.0 t C ha^{-1} cow dung and CF system decreased CO_2-C gas emission, increased carbon accumulation in above ground biomass of rice as well as carbon sequestration in soil. This treatment also helped to optimize soil pH. Based on these results, it may be concluded that continuous flooding system in combination 2.0 t C ha^{-1} increased grain yield, carbon accumulation in above ground biomass, carbon sequestration in soil and optimized soil pH.

Keywords: Carbon Accumulation in Soil-plant, Rate of Cow dung, Water Regimes, CO_2-C emission, Rice Yield, Soil pH

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Introduction

Rice is the staple food for more than half of the world population. About four-fifths of the world's rice is produced by small-scale farmers in developing countries. About 75% of the global rice production comes from irrigated rice systems because of the fact that rice varieties are more likely to be able to express their yield potential when water supply is adequate. As the world's population is still growing, the land for rice production will be diminishing, especially in Asia (Bishwajit *et al*., 2014). Before Green Revolution, farmer's of rice based countries cultivate low input crop varieties for their food production and cropping intensity was also very low as a result, soil quality such as organic matter and essential plant nutrients reserve didn't affect by the above mentioned practices. Now-a-days, farmers' use high input modern crop varieties with little or no use of organic residues for their crop production. In these consequences the highest depletion of soil carbon has been observed in soils of rice growing countries like Bangladesh (Ali *et al*., 1997). In this regard, integrated use of organic manure and chemical fertilizers would be quite promising not only in providing greater stability in production, but also in maintaining better soil fertility. Because soil organic carbon (SOC) is a key indicator for nutrient cycling, improving soil physical, chemical and biological properties, crop productivity and reducing green house gases (GHGs) (Bhattacharyya *et al*., 2010). Depletion of nutrients and organic matter contents of soils can be replenished by applying cost effective and easily available cow dung. Recommended dose of nitrogen along with cow dung may overcome the former problems as a result improve rice yield. On the other hand, water level is one of the most important factors for decomposition of organic residues in soil. Researchers have shown that soil moisture could greatly enhance organic residues decomposition and CO_2 flux (Tulina *et al*., 2009). Increasing levels of CO_2 and other greenhouse gases could produce global temperatures and change the precipitation patterns. More information how the biosphere controls atmospheric CO_2 is needed to understand the earth's carbon cycle. Foremost, an understanding of source-sink relations between the atmosphere and the cultivable crops of the biosphere is needed. The contribution of soil organic matter to sustainable crop production is well recognized and established but little is known about its rates with different levels of moisture on carbon accumulation in above ground biomass and carbon sequestration in soil during rice production. Keeping in view, pot experiment was conducted to find out the effective dose of cow dung in combination with recommended doses of chemical fertilizers and water levels for carbon accumulation in above ground biomass of rice and sequestration in soil, minimized GHG and increased rice productivity.

Materials and Methods

An experiment was conducted at the experimental farm of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh (24^{0}43'43" N, 90^{0}25'77" E, 82.296 m above mean sea level), Bangladesh during 2010-2011. The area receives an average of 2666 mm of annual rainfall, about 76% of which occurs from July to September. The mean minimum and maximum temperatures during the rice growing wet season (July–October) was 26 and 32^{0}C, whereas during the dry season (November-April), was 17 and 26^{0}C, respectively. The climate of this region is subtropical and semiarid. Initial organic carbon and bulk density were 0.52% and 1.28 g cm^{-3}. Cow dung (CD) with four levels of carbon (0.5, 1.0, 1.5 and 2.0 t ha^{-1}) including control where no use of cow dung were tested in alternate wetting and drying (AWD) and W_2= continuous flooding (CF) system. Each treatment also received the recommended dose of chemical fertilizers excluding control. Cow dung was applied before set up the experiment in 2010 and 2011. In wet season (July 2010) and dry season (October 2011), factorial experiment was laid out in a complete randomized design with three replications. About 30-days-old rice seedlings (BINAdhan 7 and BRRIdhan 29) were transplanted in 2010 and 2011, respectively. Irrigation was applied to maintain a 5 cm depth of standing water during entire growth period of rice for continuous flooding (CF) system. The wetting and drying cycle consisted of flooding the pot then allowing it to dry out; the pot was then re-flooded to 5 cm above the soil surface until the next drying cycle. Nitrogen at the rate of 105 and 164 kg ha^{-1} was applied in BINAdhan 7 and BRRIdhan 29 respectively as half dose at 15 days after transplanting and the remaining half at maximum tillering stage, respectively. Different doses of nitrogen were applied in 2010 and 2011due to seasonal variation. A basal dose of 15, 24 and 11 kg P, K and S ha^{-1} for BINAdhan 7 and 30, 96, 12 and 1 kg P, K, S and Zn ha^{-1} for BRRIdhan 29, respectively was applied through triple super phosphate, muriate of potash and gypsum. Cow dung was applied to the soils as per treatment combination and mixed thoroughly. Decomposition of cow dung as carbon dioxide was measured by standard method. The CO_2-C evolved was measured at 15 days interval up to 360 DAT during experimentation.

The amount of CO_2-C was calculated by using the following formula:

$$\text{mg evolved } CO_2\text{-C/day} = \frac{(T_2-T_1)\, M \times 22}{t} \quad ....(1)$$

where,

T_1=amount of HCl used to neutralize NaOH, T_2=T_1 + amount of HCl used to dissolve precipitated $BaCO_3$, M=molarity of HCl, 22=22 mg CO_2-C/1 ml 1M HCL, t=time in days. The CO_2-C in control treatment was subtracted from the calculated value for CO_2-C release. Carbon dioxide emission was calculated up to 360 DAT of rice.

Carbon sequestration in soil (g C m^{-2} y^{-1}) was calculated using the following equiation 3:

Carbon accumulation through photosynthesis process in above ground biomass was calculated according to the following equation 2:

Carbon accumulation (t ha^{-1}) = Carbon content in grain and straw × yield of grain and straw (t ha^{-1}) ...... (2)

Carbon sequestration rate (CSR) was calculated in 0-15 cm soil depth according to the equation 3:

$$CSR = SOC_{treatment} – SOC_{control} / \text{time (year)} \quad ......(3)$$

Where, $SOC_{control}$ = soil organic carbon content in control treatment, $SOC_{treatment}$ = soil organic carbon content in cow dung treated plots and time = 1 year. Soil organic carbon sequestration was expressed in g C m^{-2} y^{-1} per 15 cm soil depth.

Crop was harvested at ripening stage and oven-dried at 65±2^{0}C to record dry matter yield. Quantitative information related to yield and yield attributing characters, grain and straw yield of rice varieties (BINAdhan 7 and BRRIdhan 29) were analyzed to obtain the effect of different levels of water and cow dung rates on paddy. Soil samples were air dried and ground to pass a 2 mm sieve before analyzed for total organic carbon and soil reaction. Soil pH was analyzed by standard method. Total organic carbon was determined by potassium dichromate ($K_2Cr_2O_7$) method (Ryan *et al*., 2001). Data collected was subjected to analysis of ANOVA. Duncan's Multiple Range Test (DMRT) was used for mean separation, where differences significant at 5% level of probability.

Results

Effect of different water levels on yield and growth of rice, CO_2-C, organic carbon content and pH of soils are presented (Table 1, Figs. 1a, c, e). Yield attributing characters are the most important components for the performance of rice yield. Data indicated that different water levels had a significant effect on yield contributing characters of rice. Maximum plant height, tillers hill^{-1}, panicle length, filled and unfilled grains panicle^{-1}, 1000 seed weight, grain and straw yields were observed in CF system in both years except tillers hill^{-1} in 2010 and 1000 seed weight in 2011. Minimum yield contributing characters were found in AWD system. Mean increase of tillers hill^{-1} (22.99%), filled grains panicle^{-1} (34.99%) were found in CF system over AWD in 2011, respectively. Regarding water levels, CF had a significant effect on grain yield of rice. Minimum grain yield was observed in AWD system, which increased to the maximum for CF in both the years. Grain yield was increased 17 and 19% in case of CF over AWD in 2010 and 2011, respectively. Maximum CO_2-C emission was found in AWD condition at different durations except 180 and 360 DAT. Among the soil sampling durations, highest organic carbon content (0.65%) was obtained at 180 DAT in CF treated pots. Continuous flooding condition showed lower pH in soil than AWD system and it was the maximum at different durations except 30 DAT. Alternate wetting and drying system produced higher pH value in all the studied durations except 30 DAT. Maximum carbon accumulation was found in continuous flooding system in 2011. The lowest carbon accumulation was obtained from alternate wetting and drying system in 2010. Continuous flooding system produced 16.84 and 16.96% higher carbon accumulation than alternate wetting and drying system in 2010 and 2011, respectively. Mean increase of carbon sequestration (449%) in soil was found in continuous flooding system against AWD system.

Different rates of cow dung had also significant effect on yield and growth of rice, CO_2-C emission, organic carbon and pH of soils. Carbon rate from cow dung (2.0 t C ha^{-1}) increased plant height, tillers hill^{-1} and grain yield of rice in 2010 and 2011. Minimum yield contributing characters were obtained from control pots where no cow dung were applied except 1000 seed weight in 2010. Mean increase in plant height was 14.97, 26.80, 25.18, 28.04% in 2010 and 37.44, 33.95, 42.49 and 47.70% in 2011 in case of 0.5, 1.0, 1.5 and 2.0 t C ha^{-1} respectively as compared to control. Similar trends were observed for no. of tillers hill^{-1}, panicle length, filled grains panicle^{-1} except 1000 seed weight and unfilled grains panicle^{-1} of rice. Data indicated that application of different rates of cow dung had significant impact on grain yield of rice. Highest grain yield was obtained from 2.0 t C ha^{-1} treated pots in 2010. Different carbon rates produced significant difference in 2010 and the lowest grain yield was found in control. Mean increase in grain yield was 323, 386, 400 and 443% and 134, 154, 216 and 269% in case of 0.5, 1.0, 1.5 and 2.0 t C ha^{-1} in 2010 and 2011, respectively compared to control. Similar trends were found in straw yield of rice in 2010 and 2011 (Table 1). Maximum CO_2-C emission was obtained at 60 DAT. Among the carbon rates, 0.5 t C ha^{-1} produced the maximum CO_2-C emission in 60 DAT and 2.0 t C ha^{-1} produced the highest CO_2-C in 180 and 360 DAT (Fig. 1b). Organic carbon content results were statistically significant except 30 days after transplanting of rice. Carbon rate (1.5 t C ha^{-1}) produced the highest organic carbon content (0.73 and 0.75%) at 30 and 180 DAT but 2.0 t C ha^{-1} produced the highest organic carbon at 360 DAT (Fig. 1d). Lowest organic carbon content was obtained from control treatment. Effect of carbon rate on pH was not statistically significant in all the estimated dates (Fig. 1f). At 360 DAT, the highest pH values were found in 2.0 t C ha^{-1} treated pots. Carbon accumulation was significantly increased by different doses of cow dung. Maximum carbon accumulation was found in 2.0 t ha^{-1} in both the years. In above ground biomass, carbon accumulation was higher in 2011 than in 2010 irrespective of all the carbon rates. Mean increase of carbon accumulation was 426, 437, 470, 478 and 201, 276, 323, 386 over no residue in 2010 and 2011, respectively. Different doses of carbon performed significant difference on carbon sequestration in soil (Fig. 2). Maximum carbon sequestration was found in 2.0 t C ha^{-1} followed by 0.5 t C ha^{-1} treated soils (Fig. 2j). Lowest carbon content was obtained from no residue treated pots. Mean increase of carbon sequestration was 0.68, 0.06, 0.13, 1.05 g C m^{-2} per 15 cm soil using 0.5, 1.0, 1.5 and 2.0 t C ha^{-1} over no residue treated pots, respectively.

The interactive effect of water management and carbon rates also showed significant differences on yield and yield attributing characters of rice (Table 1). In 2010, maximum plant height was found in 1.0, 1.5 and 2.0 t C ha^{-1} in combination with CF system. Mean increase in plant height was 34 and 59% in $W_2 \times CD_{2.0}$ treatment compared with $W_1 \times CD_{0.0}$ treatment in 2010 and 2011, respectively. The highest total tillers hill^{-1} were obtained from $W_1 \times CD_{2.0}$ and $W_2 \times CD_{0.5}$ treated pots in 2010 and 2011, respectively. $W_2 \times CD_{1.5}$ produced the highest panicle length of rice and the lowest panicle length was found in $W_2 \times CD_{0.0}$ and $W_1 \times CD_{0.0}$ in 2010 and 2011. Maximum filled grain was found in $W_2 \times CD_{2.0}$ followed by

$W_2 \times CD_{1.5}$, $W_2 \times CD_{0.5}$ in 2010. In 2011, maximum filled grains were obtained from $W_2 \times CD_{2.0}$ treatment. The lowest grain number was observed in no residue treated pots irrespective of different water management levels. Maximum unfilled grains were found in $W_1 \times CD_{2.0}$ treatment both the years. In 2010, the highest 1000 grains weight was observed in pots where continuous flooding system in combination with 2.0 t C ha^{-1}. On the other hand, treatment $W_1 \times CD_{1.0}$ produced the highest 1000 seed weight in 2011. Maximum mean value of grain yield was observed in case of CF system along with 2.0 t C ha^{-1}followed by $W_2 \times CD_{1.5}$ treatment in 2010. Treatment $W_2 \times CD_{2.0}$ also produced higher grain yield than other treatments in 2011. The lowest grain yield was found in $W_1 \times CD_{0.0}$ and $W_2 \times CD_{0.0}$ treatments in both the years. However, maximum straw yield was found in $W_2 \times CD_{2.0}$ treatment in both the years.

Discussion

Alternate wetting and drying increased 2% more CO_2-C emission than CF system. Good aeration is an important factor for the proper activity of microorganisms involved in the decomposition of organic matter. As a result, AWD condition enhanced the oxidation process of organic residues after transplanting of rice. Soil moisture could greatly enhanced organic residue decomposition and CO_2 flux (Tulina *et al*., 2009) or reduces it (Iqbal *et al*., 2009). On the other hand, under anaerobic condition such as CF system, fungi and actinomycetes are almost suppressed and only a few bacteria occur in anaerobic decomposition (Hossain and Puteh, 2013). The low microbial activities at lower C:N ratio with non-labile C content showed non-significant difference in continuous flooding system resulting in higher stability of organic carbon in soil. Continuous flooding system increased yield and yield attributing characters of rice. Nitrogen is one of the most yield limiting in rice production in Bangladesh. In AWD condition, nitrogen use efficiency is lower than CF system due to enhanced nitrifying activities of soil microorganisms. Dong *et al*. (2012) reported that major loss of fertilizer N occurred through ammonia volatilization amounting to 21% and 13% of the applied N in the AWD and CF treatments, respectively. They also reported that loss of fertilizer through nitrification-denitrification was 6 fold higher under AWD than CF. Plant height, tillers $hill^{-1}$, panicle length, filled grains $panicle^{-1}$, 1000 grain weight, grain and straw yield of rice were decreased with the increase of water stress except tillers $hill^{-1}$ and 1000 seed weight in 2011 (Oliver *et al*., 2008). Yield contributing characters were significantly influenced by the application of cow dung and chemical fertilizers reported by Babu *et al*. (2001). Flooded soil increased organic carbon and improved soil reaction are reported (Snyder, 2012). Incorporation of well decomposed cow dung with chemical nitrogen into soil can be a strong means for controlling soil nitrogen dynamics and reducing leaching of fertilizer nitrogen, because cow dung did not use soil nitrogen through immobilization as well as adsorbed applied nitrogen by their great surface areas (Wopereis *et al*., 2009). As a result, cow dung incorporation performed better yield performance of rice due to effective synchronization of nutrient release with crop demand. Similar results were observed by Liza *et al*. (2014). Organic residues decreased pH in post harvest soil due to the production of organic acid, phenolic and carboxylic compounds and secretion of growing biomass (Rezig *et al*., 2013). Higher dose of carbon increased crop yield. Complementary application of organic and inorganic fertilizers increase nutrient synchrony and reduces losses by converting inorganic nitrogen to organic nitrogen form (Kramer *et al*., 2002). It may be concluded that higher dose of organic material in combination with chemical fertilizers especially nitrogen supplied significant amount of plant nutrients during crop production and improved soil fertility. Soil organic matter undergoes mineralization and releases substantial quantities of nitrogen, phosphorus, sulfur and smaller amount of micronutrients (Rahman *et al*., 2013). Animal manure is considered a valuable nutrient source when applied to soil at different rates commensurate with good agronomic practices (Duffera *et al*., 1999). Higher dose of carbon with continuous flooding system produced maximum carbon accumulation in above ground biomass and sequestrated more carbon in soil.

Combined use of chemical fertilizers with 2.0 t C ha^{-1} cow dung in CF system yielded better performance to reduce CO_2-C gas emission, increased carbon accumulation in above ground biomass, carbon sequestration in soil through carbon content in soil, optimized soil pH and increased rice productivity. Reduced plant height, no. of effective tillers $hill^{-1}$, grain yield, straw yield and increased CO_2-C emission were found with the increasing water stress as AWD system in combination with chemical fertilizer and 2.0 t C ha^{-1}. Based on these results, it may be concluded that CF is better than AWD system to feed our over growing people in the rice growing countries as well as this practice increased carbon harvest from atmosphere and carbon sequestration in soil. Based on these results, it may be concluded that continuous flooding system in combination 2.0 t C ha^{-1} increased grain yield, carbon accumulation in above ground biomass, carbon sequestration in soil and optimized soil pH.

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Table 1. Effect of cow dung doses and water levels on yield and yield attributing characters of rice

Treat-ment	Plant height (cm)		Tillers hill^{-1} (no.)		Panicle length (cm)		Filled grain panicle^{-1} (no.)		Unfilled grain (no.)		1000 seed weight (g)		Grain yield (g plant^{-1})		Straw yield (g plant^{-1})	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Water management (W)																
W_1	50.96 b	64.55 b	6.60	7.22 b	19.13	22.77	45.13 b	81.60 b	27.53 b	22.47	23.24	19.51	11.28 b	15.25 b	13.18 b	20.78 b
W_2	52.33 a	69.12 a	6.09	7.49 a	19.83	23.15	63.41 a	85.60 a	27.88 a	23.00	22.78	19.16	13.19 a	18.13 a	15.27 a	23.91 a
Carbon in cow dung (CD)																
0.0	43.40 c	50.13 d	2.84 c	2.61 b	15.18 c	18.57b	36.40 b	53.84 e	13.95 c	16.83 d	23.91	16.86b	2.98 d	6.55 d	2.78b	5.01e
0.5	49.90 b	68.90 bc	6.84 ab	8.94 a	20.13 ab	23.93a	53.33 a	78.50 d	31.25 a	19.00 c	23.51	20.60a	12.61 c	15.35 c	17.84a	27.55b
1.0	55.03 a	67.15 c	6.50 b	8.00 a	20.67 ab	24.03a	63.05 a	84.34 c	23.80 b	23.17 b	22.26	20.47a	14.49 b	16.67 c	16.44a	22.33d
1.5	54.33 ab	71.43 ab	7.17 ab	8.34 a	21.97 a	24.13a	55.32 a	94.67 b	35.18 a	28.00 a	22.43	19.93a	14.91 b	20.72 b	17.17a	25.56c
2.0	55.57 a	74.07 a	8.34 a	8.89 a	19.44 b	24.13a	62.25 a	106.67 a	34.35 a	26.67 a	22.93	18.80a	16.19 a	24.16 a	16.89a	31.27a
Interaction (W×CD)																
$W_1 \times CD_{0.0}$	41.60 d	46.73 e	2.67 e	2.78 b	14.43 b	18.80	35.20 e	51.00 g	13.00 f	8.33 f	23.78 ab	15.88e	3.06 e	5.31 f	2.78b	4.65e
$W_1 \times CD_{0.5}$	51.27 abc	69.07 b	8.00 ab	8.78 a	20.13 a	23.53	37.60 d	76.33 e	29.30 bc	16.33 e	23.03 abc	20.09a-d	12.43 d	16.90 c	16.34a	14.19d
$W_1 \times CD_{1.0}$	53.53 ab	61.43 c	5.33 d	7.87 a	20.13 a	24.20	43.37 cd	80.67 d	21.00 de	20.67 cd	22.68 abc	21.90a	13.12 cd	12.69 d	15.43a	25.00c
$W_1 \times CD_{1.5}$	53.07 ab	71.65 ab	8.00 ab	7.67 a	21.67 a	23.53	65.30 cd	89.33 c	35.67 ab	33.00 a	21.28 bc	21.32ab	13.50 cd	20.42 b	15.77a	26.38c
$W_1 \times CD_{2.0}$	55.33 ab	73.87 a	9.00 a	9.00 a	19.27 a	23.80	59.27 bcd	98.00 b	38.70 a	34.00 a	20.45 c	18.36de	14.27 bc	20.95 b	15.55a	33.68a
$W_2 \times CD_{0.0}$	45.20 cd	53.53 d	3.00 e	2.44 b	15.93 b	18.33	36.83 e	56.67 f	14.90 ef	25.33 b	24.04 ab	17.85de	2.90 e	7.79 e	2.78b	5.36e
$W_2 \times CD_{0.5}$	48.53 bcd	68.73 b	5.67 cd	9.10 a	20.13 a	24.33	42.33 ab	79.67 d	33.20 ab	21.67 cd	24.00 ab	21.11abc	12.10 d	13.80 d	19.34a	24.74c
$W_2 \times CD_{1.0}$	56.53 a	72.87 ab	7.67 abc	8.11 a	21.20 a	23.87	68.30 abc	89.00 c	26.60 cd	25.67 b	21.84 bc	19.04bcd	15.47 b	20.66 b	17.44a	28.86b
$W_2 \times CD_{1.5}$	55.60 ab	71.20 ab	6.33 bcd	9.00 a	22.27 a	24.73	45.50 a	100.00 b	34.70 ab	23.00 bc	23.59 ab	18.55cd	17.39 a	21.01 b	18.57a	30.09b
$W_2 \times CD_{2.0}$	55.80 a	74.27 a	7.67 abc	8.78 a	19.60 a	24.46	79.00 a	115.30 a	30.00 bc	19.33 d	25.42 a	19.24bcd	18.10 a	27.37 a	18.23a	30.48b
CV(%)	8.16	4.01	20.79	13.59	12.45	9.20	12.97	2.26	13.45	7.12	7.06	7.79	7.60	7.50	27.55	5.89

Figures sharing the same letter do not differ statistically at $P \leq 0.05$ by LSD test, W_1-alternately wetting and drying and W_2-continuous flooding and carbon rate in rice straw 0.0, 0.5, 1.0, 1.5 & 2.0 t ha^{-1}.

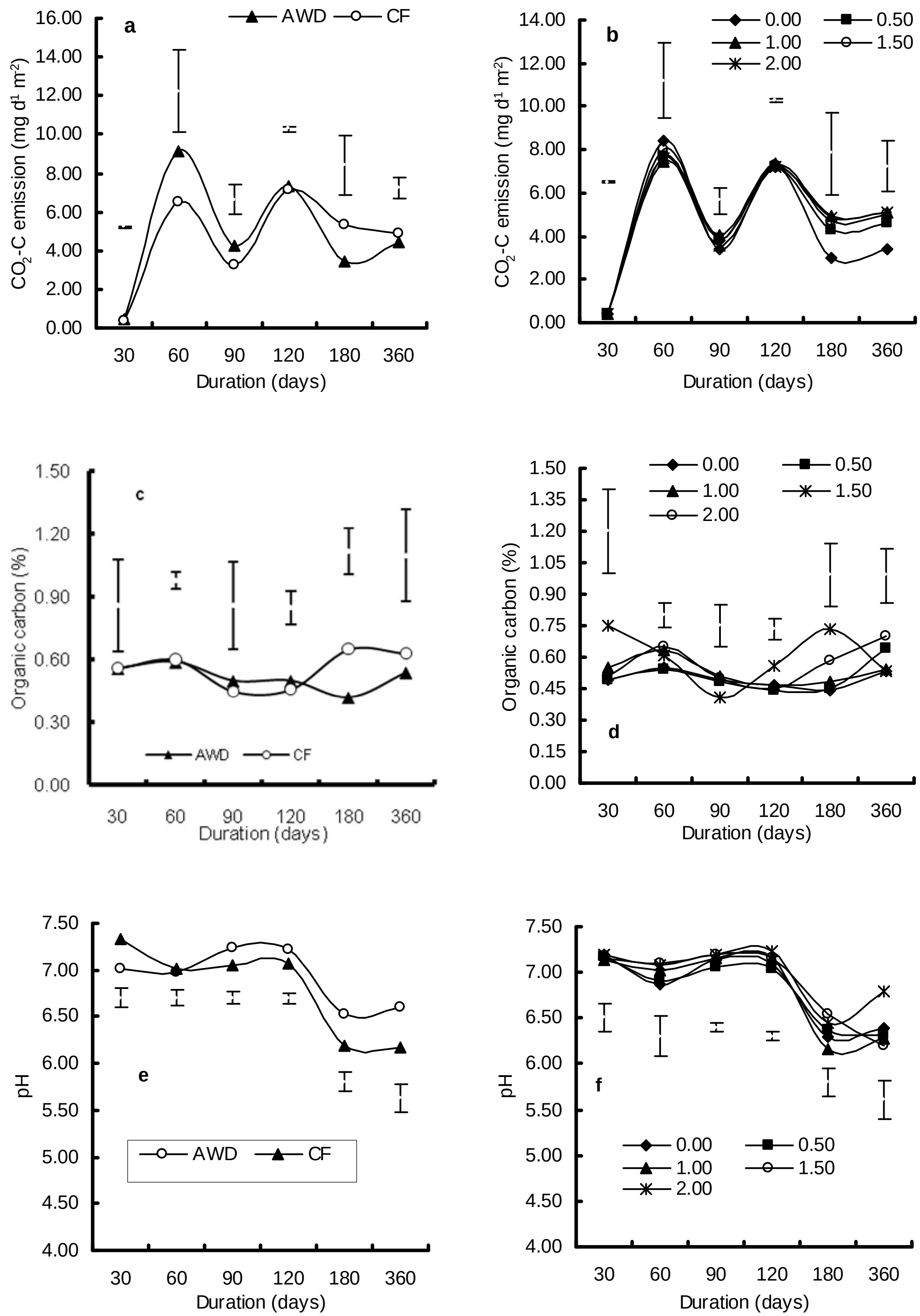

Fig. 1: Effect of cow dung and water levels on soil. a & d : carbon dioxide carbon emission b & e : organic carbon (%) and c & f : soil pH

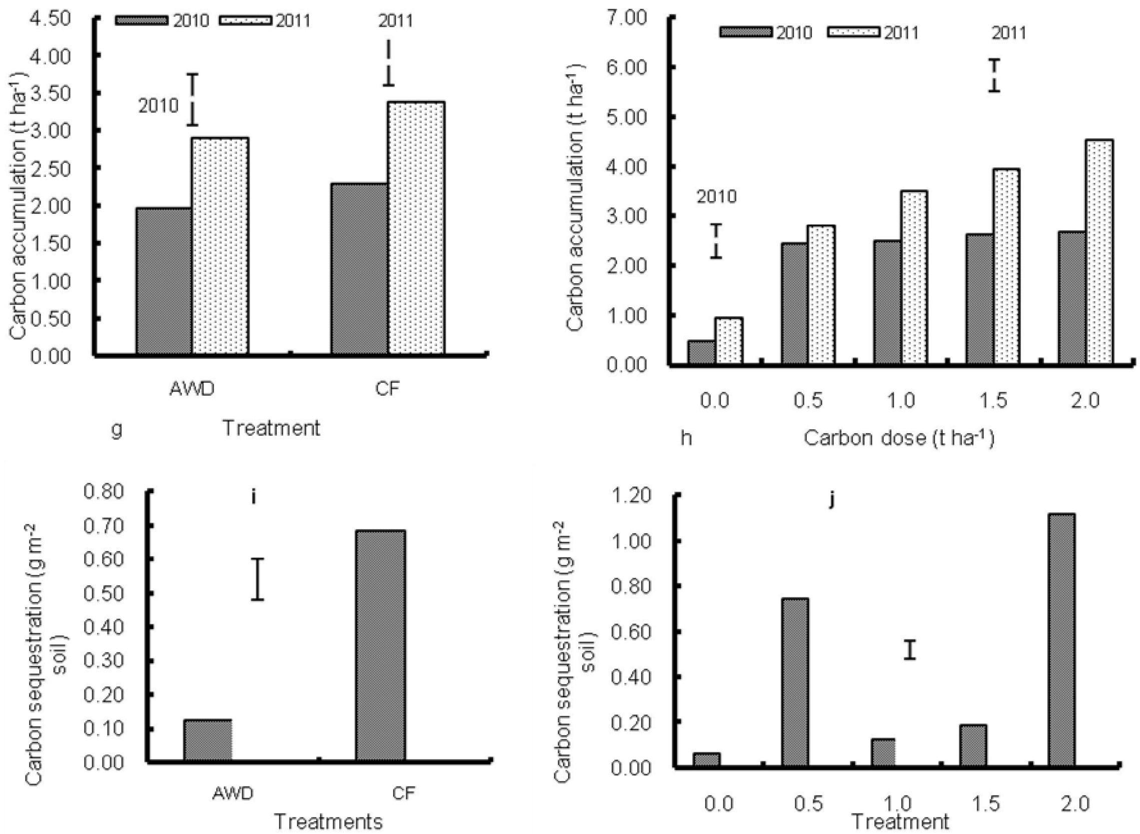

Fig. 2 : Effect of cow dung and water levels on soil. g & h : carbon accumulation, i & j : carbon sequestration in soil