

Carbon Dioxide Flux Density in Cultivated Rice Paddy Field

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ABSTRACT

The carbon dioxide flux density in a subtropical cultivated rice paddy field were determined over four crop seasons (two consecutive years) at five stages of rice plant development, transplanting, active tillering, booting, flowering and ripening, and an idle period between crops. During 24 h sampling periods at those stages, the CO₂ flux densities were measured and found to be -2,000 to 55,000 mg CO₂/m²/day in the first year and 600 to 29,000 mg CO₂/m²/day in the second year in acrylic chambers covering rice plants. The CO₂ flux densities in glass domes without plants but with soil were -700 to 6,000 mg CO₂/m²/day in the first year and 147 to 4,500 mg CO₂/m²/day in the second year. The data for the CO₂ flux density over an entire year are extrapolated. Although our non-controlled environment experiments have inherent drawbacks, the collected data indicate that continuous rice cultivation has a tendency to result in increased CO₂ emissions.

Key Words: cultivated rice paddy field, CO₂ flux density

1. Introduction

It is believed that global climate changes in the 20th century were due in part to the greenhouse effect, which results in increasing CO₂, CH₄, N₂O, CFCs and O₃ gases in the convection layer of the atmosphere, and that these detrimental effects will continue to intensify due to human activities, such as forest destruction and industrial air pollution. More than 50% of the total current greenhouse effect is attributed to CO₂ production (Houghton *et al.*, 1990). Hall (1989) estimated that CO₂ levels are now increasing by 3 ppb per year throughout the biosphere. He offered evidence that atmospheric carbon dioxide remained constant at 270 - 290 mg/kg for several centuries and has been gradually increasing over the past two hundred years. The atmospheric CO₂ concentration had reached to a level of 310 mg/kg by 1950, and of 350 mg/kg by 1990 (Houghton *et al.*, 1992). Sundquist (1993) reported that over 200 ppb of carbon released into the biosphere in the past two hundred and fifty years can be directly attributed to deforestation and fossil fuel combustion.

A great deal of research has focused on the effects of CO₂ and temperature on the development and growth of rice (Baker *et al.*, 1992; Manalo *et al.*, 1994; Ziska *et al.*, 1996; Seko and Nishimura, 1996; Rowland-Bamford *et al.*, 1996; Vu *et al.*, 1997; Matsui *et al.*, 1997). Results generally show that high CO₂ levels in conjunction with high temperatures produce maximum yields. Rice plants and paddy soils have

been shown to emit CO₂ during cultivation (Duenas *et al.*, 1995; Oechel *et al.*, 1997). The oxidation of hydrocarbons and related compounds (from the burning off of crop stalks and the mild oxidation of respiration) produces large amounts of CO₂, while photosynthesis by growing green plants requires the consumption of substantial amounts of CO₂. Hence, the relationship between variations in the content of CO₂ in the atmosphere and plant growth must be properly understood.

According to Cole *et al.* (1993), agricultural fields are neither a major source nor a sink of atmospheric carbon, regardless of the length of time they are in production; this suggests that carbon inputs and outputs in most agricultural croplands are essentially balanced. Overdieck (1993) showed that neither the number of plant buds nor the mean area per leaf were significantly altered due to CO₂ enrichment although the leaf area index increased by 1.4 units and the dry weights of all the main organs were increased. In a study on tillage-induced CO₂ emission from soil, Reicosky (1996) found that soil after moldboard plowing lost 13.8 times as much CO₂ as untilled soil, much more than the average 4.3 times resulting from the use of other tilling tools. Sauerbeck (1993) suggested that reduced soil tillage, improved recycling of organic waste, and rotation of crops were likely to reduce soil carbon losses.

More recently, Paustian *et al.* (1997) reported that since agricultural soils have a significant CO₂ sink capacity, the building up of soil carbon must cause the input of organic

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栽培水稻之田間二氧化碳通量密度

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摘 要

二氧化碳在亞熱帶栽培水稻田之通量密度，經二年共四期稻作期間，在水稻植株發育的五個階段—插秧期、分蘖盛期、孕穗期、開花期及糊熟期—以及在兩期作之間的休閒期測量二氧化碳通量密度而估算。在各生長階段以壓克力罩罩住水稻植株，測量連續24小時之二氧化碳通量密度為-2,000至55,000 mg/m²/day（第一年）及600至29,000 mg/m²/day（第二年），另以鐘形玻璃罩罩住土壤（沒有水稻植株），測量二氧化碳通量密度為-700至6,000 mg/m²/day（第一年）及147至4,500 mg/m²/day（第二年）。以外推各生長期的數據推算整年中之二氧化碳通量密度。在未能控制的戶外環境下所做的實驗，有其固有的缺點，但本實驗所得的數據顯示耕種水田有增加二氧化碳自田間放出之趨勢。

matter to soil to increase and soil organic matter decomposition rates to decrease. Karube *et al.* (1992) and Gaskins and Weyant (1993) proposed biotechnological fixation of CO₂ as a means of reducing CO₂ emissions. Sitaula *et al.* (1995) suggested that soil acidification also effects CO₂ emissions. Calculation of net CO₂ sinks and emissions as well as assessment of mitigation options has also been reported by Kokorin *et al.* (1996). The present study was designed to determine the CO₂ flux density in a subtropical paddy field during rice cultivation.

II. Materials and Methods

1. Experimental Plot

The experiment was conducted in a 1 ha rice field located at the Agriculture Experimental Station of the College of Agriculture, National Taiwan University, Taipei, Taiwan. The field, which exists in a subtropical zone of northern Taiwan (25°0'N, 121°30'W), has been used for rice production for several decades. Its topsoil (0–15 cm) is sandy loam in texture with an organic matter content of 3.4%, total nitrogen 1.7 g/Kg soil, and pH 6.1.

2. Rice Cultivation

In Taiwan, rice is cultivated in two crops seasons per year, a spring crop (first crop) from March to July and a fall crop (second crop) from August to December. Each rice crop can be divided into five growing stages: transplanting, active tillering, booting, flowering, and ripening. An idle period usually separates the two crops, from January to February. The present research covered four consecutive crop seasons from August, 1994 to July, 1996. Rice plants (*Oryza sativa* L. cv. Tainung 67) were grown season-long outdoors with natural sunlight, and in a non-controlled environment. Crop details and sampling dates are presented in Table 1.

3. Apparatus for CO₂ Sampling

Acrylic chambers, 40 by 40 cm square and 65 cm tall, were used to cover four rice plants each for collecting CO₂ samples. Each chamber was equipped with a fan, a thermo-

meter, and four sampling ports each sealed with a rubber septum on the upper side of the chamber. The chamber was large enough to entirely cover four rice plants. When the rice plants grew to heights greater than 65 cm, another chamber with the same base size but with open top and bottom was placed under the original chamber and attached to it tightly with a fitting and a rubber ring seal between the two chambers. In addition, a fluted metallic curb, surrounded by a water seal to prevent air leakage, was placed beneath the base chamber and inserted in the soil. Glass domes, 500-ml in volume and 9 cm in diameter with a small opening on top, were used to cover the soil and collect air samples from plantless soil surfaces. The opening, used as a sampling port, was sealed with a rubber septum.

4. Sample Collection

Sampling dates are given in Table 1. The four acrylic chambers and six glass domes were placed in randomly chosen positions throughout the paddy field. Air samples in the chambers were collected at 2:00, 5:00, 8:00, 11:00, 14:00, 17:00, 20:00 and 23:00 hours on the first day, and at 5:00 and 14:00 hours on the second and third days. During sampling from the acrylic chambers, the fan on the upper side of the chamber was attached to a storage battery and operated. Rubber septums on the sampling ports were removed from the chambers and glass domes for half an hour prior to collecting samples to allow equilibrium of internal and external air to be achieved. Temperatures were recorded from the upper port of each chamber immediately following re-sealing with rubber septums. Air samples were collected immediately following re-sealing and 30 min later. A disposable syringe (30-ml) was inserted through the rubber septum, and 30-ml of internal air was extracted and transferred to a serum bottle. A second needle was inserted into the serum bottle septum to remove internal air when the sample was injected. The needle was stubbed up before the entire sample was inserted.

5. Measurement of Conditions Surrounding the Experimental Field

During sampling, the levels of the oxidation-reduction potential (Eh) of the experimental rice paddy field were de-

Table 1. Crop Details and Sampling Dates

Growth stage or rice	Days after transplanting	Second crop 1994	First crop 1995	Second crop 1995	First crop 1996
Transplanting	–3 – –1 ^a	Aug. 10 – 12	Mar. 6 – 8	Aug. 24 – 26	Mar. 7 – 9
Active tillering	30 – 50	Sep. 14 – 16	May 1 – 3	Oct. 3 – 5	Apr. 29 – May 1
Booting	55 – 85	Oct. 25 – 27	May 30 – June 1	Oct. 19 – 21	June 4 – 6
Flowering	70 – 110	Nov. 3 – 5	July 1 – 3	Nov. 3 – 5	June 28 – 30
Ripening	100 – 130	Dec. 6 – 8	July 17 – 19	Nov. 29 – Dec. 1	July 17 – 19
Non-tillage		Jan. 23 – 25		Feb. 4 – 6	

^aDays before transplanting.

terminated using a Hanna HI 8424 measuring instrument. The machine's oxidative-reductive electrode was inserted 10 cm depth into the soil before data were collected. Both the soil (10 cm depth) and water pH were measured using a Sentron 2001 pH meter. Light intensity was determined using a Toshiba SPI-5 lightmeter.

6. Determination of CO₂ Flux Density

Using a 1 ml disposable syringe, a 0.4 ml sample was taken from each bottle and injected into a gas chromatograph (Shimadzu GC6A, Tokyo, Japan) to determine the CO₂ content. Gas chromatography was performed using a glass column (1 m × 4 mm id) packed with Propark Q (60/80 mesh) and equipped with a thermal conductivity detector. The operating temperatures were: injection port 55°C, detector 60°C, and column 50°C. Hydrogen was employed as the carrier gas with a flow rate of 25 ml/min. All experiments were performed in triplicate.

7. Evaluation of CO₂ Release from the Rice Paddy Field

The CO₂ flux density was calculated using the formula presented by Rolston (1986):

$$f = (V/A) (\Delta C/\Delta t),$$

where f is the flux density of gas (g CO₂/m² soil/h), V is the volume of air inside the collection chamber (m³ air), A is the area of the soil covered by the collection chamber (m² soil area), and $\Delta C/\Delta t$ is the time rate for the change in the gas concentration occurring within the chamber (g CO₂/m³ air/h).

The CO₂ flux density over a period of 24 h on the sampling days was estimated by summing the total CO₂ flux density during the day. The individual daily CO₂ flux density were used to express the CO₂ flux density for each day of the entire growth stage. The sampling day was used as the mid-point day of the entire stage period, and was used to extrapolate the day forward and backward for estimating the CO₂ flux density of that growth stage. Summing the CO₂ flux density of each growth stage over an entire year, the values of the total CO₂ flux density were treated as the estimated data of the entire year.

III. Results and Discussion

The temperature of the air, paddy water and soil at the time of sampling of the two crops in 1995 were collected, and the data are shown in Fig. 1; the corresponding pH and soil Eh data are shown in Fig. 2. In all cases, temperatures were highest at noon and lowest at midnight; temperature variation also coincided with seasonal change. No soil or water temperature or pH data were collected during the final growth

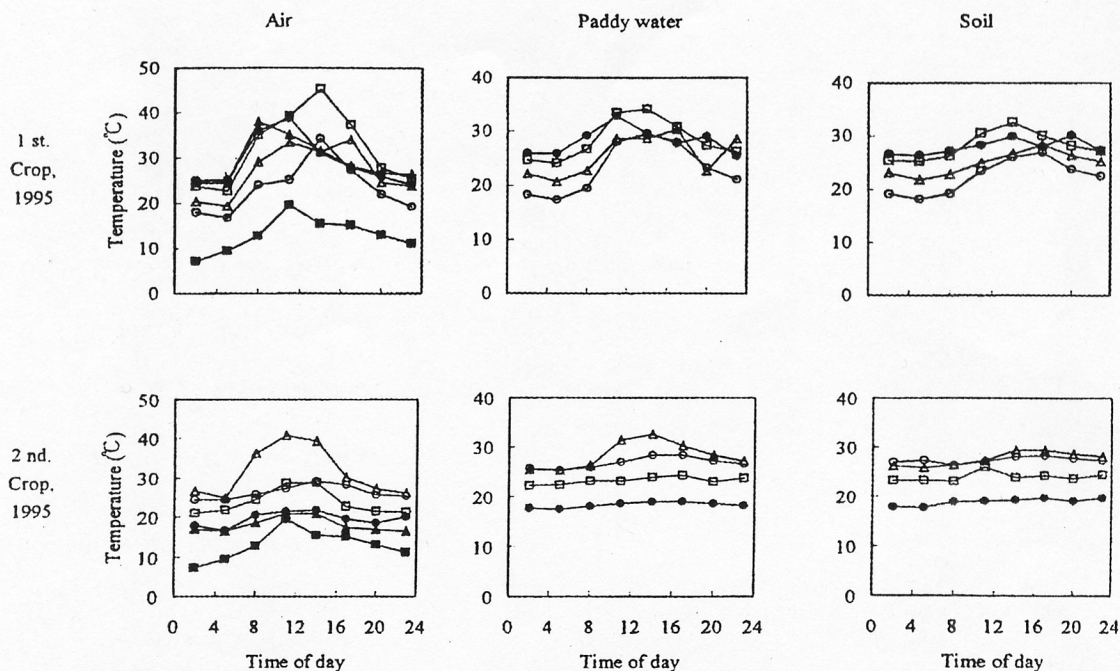


Fig. 1. Daytime and nighttime temperatures recorded on sampling days at different stages of rice plant development. (—○—), transplanting stage; (—△—), active tillering; (—□—), booting; (—●—), flowering; (—▲—), ripening; (—■—), idle stage.

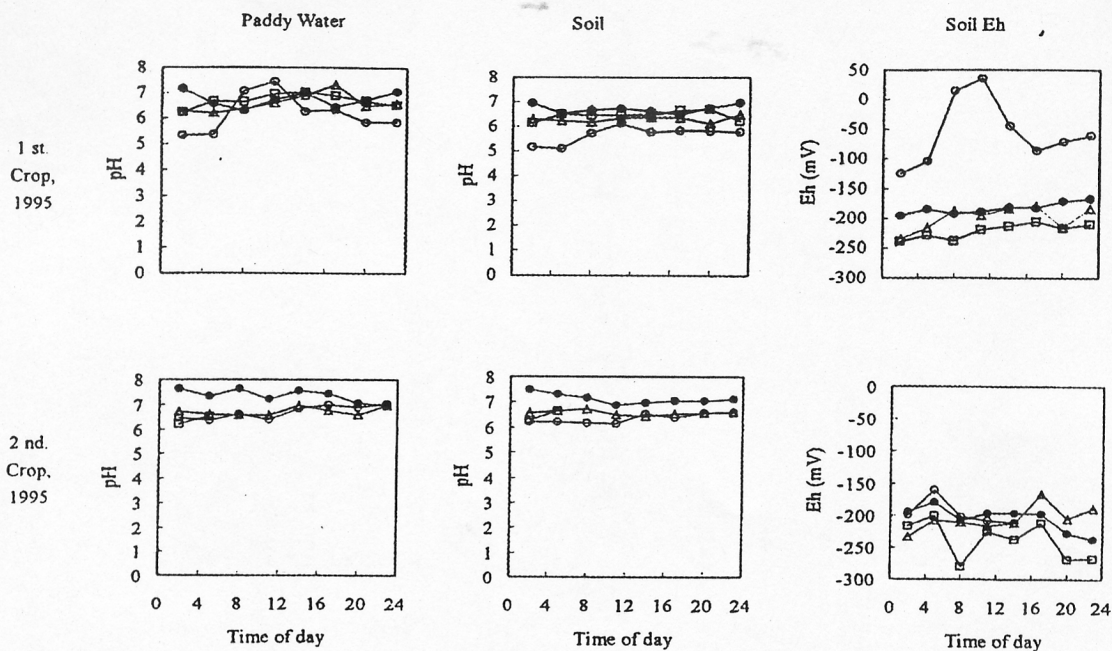


Fig. 2. Soil Eh and paddy water/soil pH values over 24 h on sampling days at different stages of rice plant development. (—○—), transplanting stage; (—△—), active tillering; (—□—), booting; (—●—), flowering; (—▲—), ripening; (—■—), idle stage.

Table 2. Ten-Day Average Air Temperatures (°C) during the Experimental Period

2nd crop season, 1994			1st crop season, 1995			2nd crop season, 1995			1st crop season, 1996		
Jul.	A	30.0	Jan.	A	15.7	Jul.	A	28.9	Jan.	A	15.0
	B	29.6		B	15.8		B	28.9		B	16.9
	C	29.4		C	15.4		C	29.2		C	15.1
Aug.	A	29.1	Feb.	A	12.7	Aug.	A	28.6	Feb.	A	14.2
	B	28.8		B	16.2		B	29.3		B	16.5
	C	28.9		C	13.7		C	29.2		C	14.4
Sep.	A	28.9	Mar.	A	16.2	Sep.	A	29.9	Mar.	A	17.5
	B	25.0		B	16.3		B	26.5		B	18.7
	C	24.6		C	18.9		C	25.2		C	19.7
Oct.	A	24.7	Apr.	A	17.9	Oct.	A	26.8	Apr.	A	16.8
	B	25.4		B	23.6		B	24.7		B	18.9
	C	20.8		C	24.8		C	23.2		C	22.1
Nov.	A	21.7	May	A	13.4	Nov.	A	21.4	May	A	23.0
	B	23.5		B	23.8		B	20.5		B	23.0
	C	21.4		C	25.8		C	17.6		C	23.9
Dec.	A	22.0	Jun.	A	27.1	Dec.	A	15.9	Jun.	A	29.0
	B	19.8		B	27.3		B	18.6		B	29.3
	C	18.6		C	29.9		C	15.0		C	28.5

Source: Central Weather Bureau, Taipei, Taiwan, R.O.C.

Notes: Temperatures refer to ten-day average temperatures (in °C). A: First ten days of the month. B: Second ten days of the month. C: Last ten days of the month.

stage since all the water had already been drained, and the soil became too hard to smoothly insert a probe. Soil Eh data indicated that the rice paddy field was in an extended reductive state.

Data for local ten-day average air temperatures are presented in Table 2. The average air temperature exceeded 25°C

from June to September every year and was below this temperature during the other months. However, the local ten-day average temperature ranged from 15°C to 30°C throughout the whole year. According to Salisbury and Ross (1985a), temperature, oxygen and CO₂ content, inorganic salt concentration and mechanical stimulation are known factors affect-

ing plant respiration, and sunlight, oxygen, CO_2 , and soil and water temperature are known to affect photosynthesis. Because these factors are complex and extremely difficult to control in the field, the experiment results are difficult to perfection. Our results are those observed at sampling times.

Variation in CO_2 flux density over 24 h on sampling days at different stages of rice plant development was measured over two years (4 crops). The results for the first year, from the second crop season of 1994 to the first crop season of 1995, are presented in Fig. 3, and the results for the second year, from the second crop of 1995 to the first crop of 1996, are presented in Fig. 4. Data collected from the acrylic chambers (with rice plants) showed variations in CO_2 flux density from -400 to $11,000$ (first year) and from -400 to $2,200$ (second year) $\text{mg CO}_2/\text{m}^2/\text{h}$ in the different sampling periods. Corresponding variations in glass dome data (without plants) were from 0 to 500 and from -600 to 300 $\text{mg CO}_2/\text{m}^2/\text{h}$.

Differences in the CO_2 flux density may be due to seasonal fluctuations in climate. Negative CO_2 flux has been attributed to the absorption of CO_2 by photosynthesis of the rice plants and paddy algae was greater than the emission of CO_2 by respiration (Salisbury and Ross, 1985a). Since these processes occur simultaneously during the growth cycles of green plants, any factor affecting respiration and photosyn-

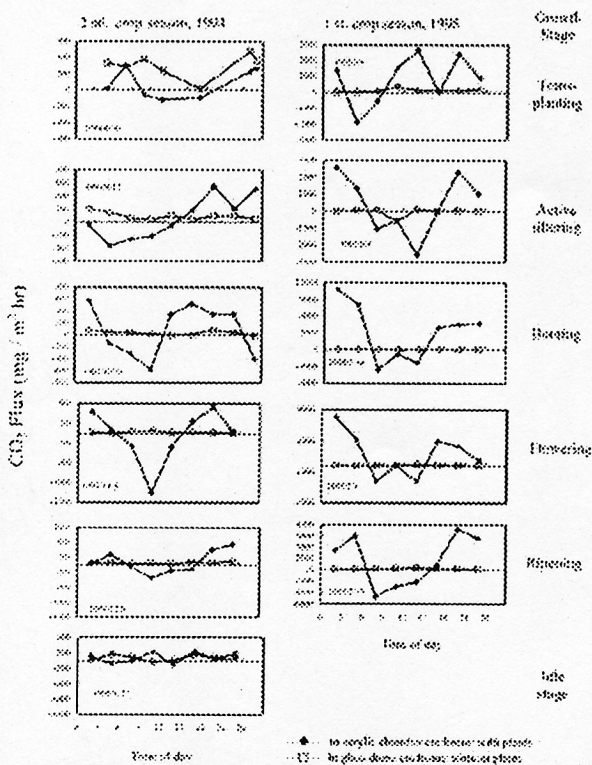


Fig. 3. CO_2 flux density over 24 h on sampling days at different stages of rice plant growth in the second crop, 1994, and in the first crop, 1995 (the first year of the experiment).

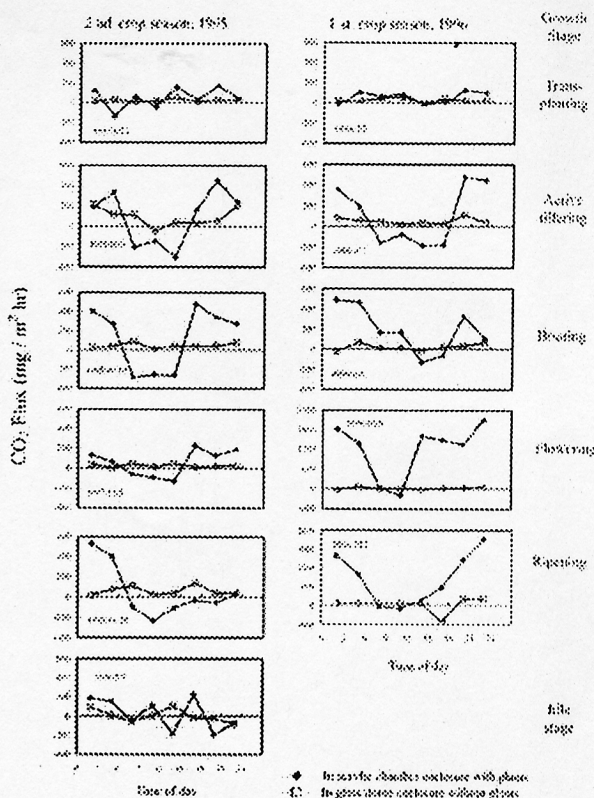


Fig. 4. CO_2 flux density over 24 h on sampling days at different stages of rice plant growth in the second crop, 1995, and in the first crop, 1996 (the second year of the experiment).

thesis will also affect CO_2 generation and absorption; CO_2 flux density will, therefore, be out of balance for the majority of the growth period.

Light is important for the consumption of CO_2 by plants. The data shown in Figs. 3 and 4 confirm that negative CO_2 flux density occurred only during daytime hours, which is in agreement with results reported by many previous researchers (Baker *et al.*, 1992; Manalo *et al.*, 1994; Seko and Nishimura, 1996; Vu *et al.*, 1997). Since growth-limiting factors, such as cloud cover, sunlight intensity and temperature are impossible to control, it was uncertain that maximum negative CO_2 flux density would occur exactly at noon on any given day. However, both respiration and photosynthesis in C_3 plants such as rice are known to occur at faster rates at temperatures ranging from 15 – 25°C (Salisbury and Ross, 1985b), which is the prevailing range in northern Taiwan. In a temperature range of 30 – 40°C , CO_2 absorption by rice plants is reduced at the same time that photosynthesis is inhibited (Salisbury and Ross, 1985b).

According to the collected data (Table 3), the variation of CO_2 flux density in the cultivated rice paddy field depended on the plant growth stage and size. During the idle period (no plants), no significant difference in CO_2 flux density was noted

Table 3. CO₂ Flux Density in the Cultivated Rice Paddy Field on Sampling Days

Growth stage of rice	2nd crop season			1st crop season		
	Sampling date	CO ₂ flux density ^a		Sampling date	CO ₂ flux density ^a	
		With plants	Without plants		With plants	Without plants
First year (1994-1995)						
Transplanting	Aug. 10	1023	5997	Mar. 6	16227	2488
Active tillering	Sept. 14	908	2338	May 1	4170	-680
Booting	Oct. 25	2106	654	May 30	55271	1423
Flowering	Nov. 3	-1984	669	July 1	34696	2248
Ripening	Dec. 6	876	1070	July 17	26854	4900
Non-tillage	Jan. 23	1340	1822			
Second year (1995-1996)						
Transplanting	Aug. 24	1205	601	Mar. 7	1366	711
Active tillering	Oct. 3	2169	2205	Apr. 29	2612	1290
Booting	Oct. 19	2928	1023	June 4	4624	545
Flowering	Nov. 3	1370	636	June 28	28775	4476
Ripening	Nov. 29	1333	1510	July 17	20195	674
Non-tillage	Feb. 4	594	147			

^aCO₂ mg/m² day.

between the acrylic chambers and glass domes.

The data also showed that there was lower CO₂ flux density in the acrylic chambers during the second crop season than during the first (Table 3). The second cultivation season lasts from August (summer) to January (winter), during which time plants grow more gradually, but the average temperature drops, and sunlight intensity and duration decrease. The environmental conditions are adequate for respiration and photosynthesis when the plants are very small and inefficient, but by the time they achieve proper size, the environmental conditions are no longer appropriate (Overdieck, 1993). First season rice crops from winter (March) to summer (July), benefit from increasingly suitable conditions in terms of extensive respiration and photosynthesis.

Special attention was given to the CO₂ flux density data collected at 5:00 and 14:00 hours for three consecutive sampling days during each of the four growing seasons (Table 4). Samples were taken from either four acrylic chambers or six glass domes. Statistical analysis of the data revealed a higher standard deviation (data not shown) due to non-controlled environmental conditions. Essentially equal levels of CO₂ flux density were noted at the same sampling time during the three consecutive days, but not across the growing season – due to changes in temperature, rainfall, or other environmental conditions. Some large differences in CO₂ flux density for the same sampling hour between the three consecutive days were due to changes in weather. However, the CO₂ flux density trend during rice cultivation can be inferred from the data.

The CO₂ flux density for an individual day in the cultivated paddy rice field was estimated by summing the total CO₂ flux density per unit area over a 24 h period in this study. In Figs. 3 and 4, data points above the x-axis refer to that there was greater CO₂ emission from the field and plants than there was absorption by plants, and data points below the x-axis

indicate greater CO₂ absorption than emission. CO₂ flux density measurements obtained on the sampling days are presented in Table 3. In each plant development stage of the second crop, the CO₂ flux density measured in acrylic chambers (with rice plants) and glass domes (without plants) was approximate due to environmental condition changes (Overdieck, 1993) as described above. However, in each plant development stage during the first crop (progressing from winter to late spring/early summer), the CO₂ flux density measured in acrylic chambers was much higher than that measured in glass domes.

Figure 5 presents the extrapolated and estimated data for average CO₂ flux density for an entire year in the cultivated rice paddy field. The data shown in Table 3 were used to express CO₂ flux density for each day of the entire stage. The total CO₂ flux density was calculated for each growth stage. The sampling days were used as the midpoint day of the entire stage period, and were used to extrapolate the day forward and backward for estimating the CO₂ flux density of this growth stage. From the extrapolated data, we noted several tendencies. The average CO₂ flux density for the paddy field cultivated with plants (acrylic chamber) was 3,816,000 and 1,362,000 mg CO₂/m²/yr for the first and second year, respectively; for soil without rice plants (glass domes), the figures were 572,000 and 381,000 mg CO₂/m²/yr, respectively. These figures support the findings of Duenas *et al.* (1995) and Oechel *et al.* (1997), who reported that the CO₂ flux density in the field increased during cultivation. The fact that CO₂ emission exceeded the assimilation of organic carbon in the cultivated rice paddy field may be attributed to an increase in the rate of decomposition of soil organic matter caused by microorganisms in subtropical cultivated soils. During cultivation, the soil organic matter decomposition is affected by the fertilizer supply, soil acidification (Sitaula *et al.*, 1995)

Table 4. CO₂ Flux Density (CO₂ mg/m²/hr) in the Cultivated Rice Paddy Field Collected at 5:00 and 14:00 Hours for Three Consecutive Sampling Days during Each of the Four Growing Seasons

Sampling day	5:00		14:00	
	With plants	Without plants	With plants	Without plants
Aug. 10, 1994	95 ± 156	15 ± 178	13 ± 102	338 ± 405
11	131 ± 152	113 ± 107	262 ± 89	364 ± 284
12	-3013 ± 219	121 ± 100	-633 ± 43	190 ± 283
Sep. 14	-47 ± 244	203 ± 121	-338 ± 55	239 ± 237
15	512 ± 433	59 ± 50	-218 ± 243	48 ± 52
16	884 ± 371	175 ± 87	-591 ± 350	33 ± 34
Oct. 25	572 ± 1042	81 ± 93	-585 ± 573	17 ± 105
26	-401 ± 2472	-19 ± 54	-433 ± 582	17 ± 144
27	340 ± 1153	19 ± 92	-458 ± 805	51 ± 101
Nov. 3	76 ± 592	3 ± 64	-267 ± 553	28 ± 26
4	23 ± 728	4 ± 110	312 ± 459	48 ± 86
5	616 ± 566	-4 ± 53	-739 ± 928	68 ± 163
Dec. 6	286 ± 357	53 ± 38	-166 ± 716	24 ± 53
7	726 ± 483	77 ± 50	501 ± 1253	46 ± 46
8	553 ± 480	75 ± 17	104 ± 575	159 ± 112
Jan. 23, 1995	-72 ± 96	168 ± 94	-102 ± 259	28 ± 230
24	-118 ± 210	168 ± 320	180 ± 263	41 ± 66
25	80 ± 101	274 ± 148	364 ± 647	201 ± 231
Mar. 6	-1902 ± 4378	10 ± 133	2631 ± 1993	111 ± 66
7	672 ± 1259	143 ± 175	300 ± 1114	-49 ± 99
8	-899 ± 2113	97 ± 58	1384 ± 1586	-88 ± 238
May 1	1360 ± 3264	68 ± 116	-2590 ± 1955	119 ± 140
2	1805 ± 2136	96 ± 208	-583 ± 1879	23 ± 68
3	1627 ± 1546	44 ± 33	2833 ± 678	29 ± 57
May 30	8097 ± 3276	114 ± 54	-2285 ± 1227	51 ± 89
31	882 ± 5990	34 ± 90	1012 ± 3402	-43 ± 139
Jun. 1	3938 ± 3655	62 ± 41	-3818 ± 2599	10 ± 123
Jul. 1	4349 ± 4167	41 ± 119	-2505 ± 3813	265 ± 293
2	11043 ± 11811	79 ± 112	-3087 ± 5234	46 ± 189
3	2826 ± 3515	56 ± 55	942 ± 2008	82 ± 93
Jul. 17	5932 ± 3425	97 ± 95	-2205 ± 1649	342 ± 209
18	2585 ± 2709	282 ± 145	-3788 ± 4387	356 ± 214
19	5211 ± 2667	159 ± 97	-3788 ± 3853	196 ± 85
Aug. 24	-173 ± 95	36 ± 26	157 ± 152	52 ± 54
25	-85 ± 161	15 ± 21	-56 ± 70	-8 ± 32
26	-10 ± 56	-5 ± 17	-54 ± 113	-41 ± 56
Oct. 3	335 ± 82	117 ± 82	-302 ± 97	40 ± 54
4	497 ± 229	64 ± 57	-264 ± 111	-1 ± 14
5	441 ± 127	44 ± 36	-131 ± 49	17 ± 28
Oct. 19	271 ± 168	40 ± 38	-262 ± 73	44 ± 59
20	283 ± 366	58 ± 43	-258 ± 90	27 ± 12
21	342 ± 115	84 ± 64	-116 ± 88	50 ± 55
Nov. 3	63 ± 150	6 ± 24	-127 ± 89	48 ± 54
4	-326 ± 151	28 ± 32	-100 ± 119	30 ± 26
5	318 ± 218	31 ± 54	-21 ± 50	19 ± 24
Nov. 29	402 ± 588	77 ± 87	-104 ± 195	39 ± 45
30	1335 ± 1741	148 ± 94	-456 ± 346	-1 ± 47
Dec. 1	283 ± 115	82 ± 60	-591 ± 332	8 ± 47
Feb. 5, 1996	156 ± 257	12 ± 136	-183 ± 109	107 ± 164
6	52 ± 585	-23 ± 68	241 ± 111	141 ± 111
7	-11 ± 576	112 ± 273	10 ± 606	28 ± 146
Mar. 7	104 ± 47	22 ± 18	-15 ± 225	1 ± 18
8	175 ± 226	19 ± 12	417 ± 133	160 ± 62
9	51 ± 122	22 ± 22	6 ± 69	6 ± 11
Apr. 29	194 ± 175	60 ± 27	-189 ± 163	37 ± 123
30	169 ± 88	55 ± 23	-202 ± 147	14 ± 41
May 1	355 ± 217	33 ± 33	360 ± 606	30 ± 22
Jun. 4	469 ± 128	71 ± 146	131 ± 183	-14 ± 141
5	164 ± 114	61 ± 34	13 ± 108	74 ± 66
6	41 ± 225	104 ± 61	-125 ± 205	23 ± 17
Jun. 28	1398 ± 386	164 ± 67	1607 ± 273	179 ± 105
29	556 ± 330	183 ± 158	289 ± 207	272 ± 251
30	1061 ± 523	269 ± 124	-1120 ± 1911	197 ± 78
Jul. 17	992 ± 235	62 ± 33	167 ± 404	44 ± 56
18	1327 ± 1931	-5 ± 70	-3 ± 370	83 ± 86
19	1043 ± 596	267 ± 124	-600 ± 802	133 ± 116

Note: Statistical analytic values are in this Table, each value corresponds to samples taken from either four acrylic chambers (with plants) or six glass domes (without plants).

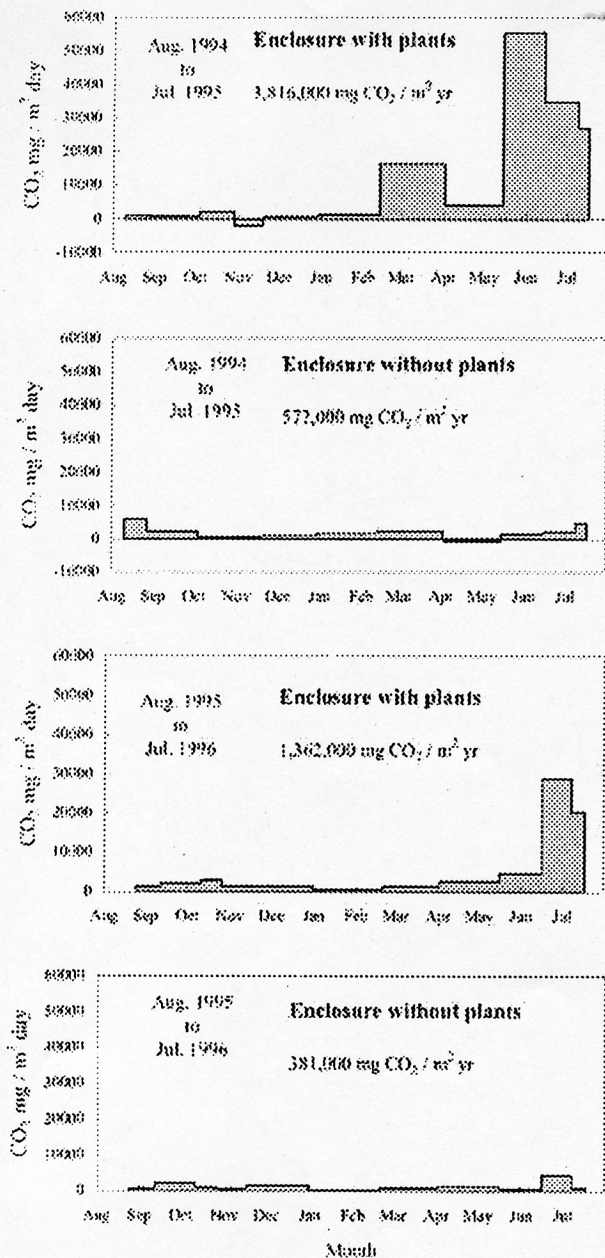


Fig. 5. Estimated CO_2 flux density over one year, using the data give in Table 3 as the one-day CO_2 flux density of each growth stage period.

and tillage (Reicosky, 1996; Sauerbeck, 1993). All in all, cultivation of paddy rice results in increased CO_2 emission. Agricultural ecosystems play a important role in the production and consumption of greenhouse gases, specifically, carbon dioxide. The CO_2 flux density in the cultivated rice paddy field studied here was modulated by the plant development stage and climatic conditions. The first crop of rice cultivation in the subtropical area of northern Taiwan extends from

March (spring) to July (summer). In the first crop, the effects of larger plants and higher temperatures in the later stage of rice growth lead to higher CO_2 flux density compared to the CO_2 flux density in the second crop. However, in the cultivated land enclosure without plants (as in fallow land), only soil microorganism activity affected CO_2 release. The collected data from this study indicate that continuous rice cultivation has a tendency to result in increased CO_2 emissions.

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