Effect of marsh reclamation on heterotrophic soil respiration in Sanjiang Plain, Northeast China

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Abstract
The Sanjiang Plain is the largest low-altitudinal swampy plain in China where has been strongly affected by human activities particularly the conversion of marsh to cropland. Four plots of *Carex lasiocarpa* marsh, *Deyeuxia angustifolia* marsh, rice field and dryland were selected in this study to evaluate the effect of marsh reclamation on heterotrophic soil respiration. Results showed that the seasonal changes of heterotrophic soil respiration from *C. lasiocarpa* marsh and *D. angustifolia* marsh were identical with a single-peak. The largest values appeared in summer and the lowest ones appeared in winter. The seasonal variation of heterotrophic soil respiration from dryland was the same as the marshlands, but the seasonal course of heterotrophic soil respiration from rice field changed and the peak values were postponed in autumn. The carbon effluxes by heterotrophic soil respiration from *C. lasiocarpa* marsh, *D. angustifolia* marsh, dryland and rice field were 3.14±0.45, 4.81±0.68, 2.85±0.38 and 2.18±0.31 t C/ha/a, respectively. Significant relationships were found between temperature and heterotrophic soil respiration from *C. lasiocarpa* marsh, *D. angustifolia* marsh and dryland, and Q_{10} values were 2.1, 2.5 and 1.8, respectively. The relationships between heterotrophic soil respiration and soil moisture/water table were best described by quadratic equations.

Key Words
Marsh, reclamation, farmland, heterotrophic soil respiration.

Introduction
Wetlands now contain a considerable share of the terrestrial carbon pool with their estimated reservoir of 225 Gt C and serve as a significant sink for atmospheric carbon (IPCC 2000). CO_2 evolution from soil is one of the major components of the global C cycle and the minor change of soil respiration maybe result in a significant influence on atmospheric CO_2 concentration which would further enhance climate change (Schlesinger and Andrews 2000). Land use change has the potential to enhance or reduce soil respiration. The Sanjiang Plain is the largest low-altitudinal marshy plain in Northeast China. Large areas of marsh have been converted into agricultural lands since late 1940s and now the Sanjiang Plain has become one of the areas with the most intensive land use/cover changes in China (Liu and Ma 2002). To date, however, no soil CO_2 efflux data on marsh have been published that conclusively indicate whether reclamation could actually decrease rather than increase the decomposition rate in China. The present study was undertaken to investigate the soil CO_2 efflux in relation to land-use change of freshwater marsh in the Sanjiang Plain, China.

Methods
Site description
This study was carried out at the Sanjiang Mire Wetland Experimental Station (47°35′N, 133°31′E), China. The average altitude is between 55.4 and 57.9 m. The study site is in a seasonal frozen zone and the non-frost period is 125 days. In 2004, annual precipitation was 431.6 mm, with nearly 55% of which fell in May and July. Daily mean air temperature was 2.3℃. Before the intensive reclamation, *Carex lasiocapa* and *Deyeuxia angustifolia* were the dominant vegetations in the Sanjiang Plain (Liu and Ma, 2002). Agricultural conversion of marsh to irrigated rice and dryland soybean is the prevalent practices in this region. Therefore, four sites of *C. lasiocapa* marsh, *D. angustif*olia marsh, rice field and dryland to investigate the effect of land-use change on soil CO_2 emissions from freshwater marsh in the Sanjiang Plain. *C. lasiocap*a marsh is continuously flooded and *D. angustifolia* marsh is seasonal flooded. Marsh plants burgeon in late May and defoliate in mid-October, respectively. The dryland and rice field were both converted from marsh in 1993 and 1997 where crops were planted with one harvest per year. Characteristics of the soils in the experimental plots are listed in Table 1.

Table 1. Characteristics of soil in the experimental plots.

Land types	SOC (g/kg)	DOC (g/kg)	TN (g/kg)	C/N	pH
C. lasiocapa marsh	268.89±41.27	6.31±0.53	16.11±3.12	18.59	5.84
D. angustifolia marsh	105.63±24.2	3.0±0.27	9.37±2.14	13.03	5.68
Dryland	21.92±5.99	0.68±0.37	2.40±0.57	12.46	6.34
Rice field	24.94±6.13	0.91±0.54	3.33±1.04	11.43	5.85

CO_2 efflux measurements

In *C. lasiocarpa* marsh and *D. angustifolia* marsh, three neighboring plots at each site were established for soil CO_2 efflux (i.e., heterotrophic respiration from soil organic carbon decomposition) measurements. In the summer of 2003, the plots were trenched to a depth of 60cm according to different soil layers from top to bottom, and then the soil was backfilled based on the normal sequence of the soil layers from bottom to top with the intention of excluding root respiration and the further growth of new roots. We started the measurement of soil CO_2 efflux at the beginning of 2004. Newly deposited litter was removed, and litter nets served to prevent the further accumulation of litter. Aboveground parts of the ground vegetation were removed from all sample plots, and the plots were kept free of vegetation by regular cuttings.

Three bare plots (2m×2m) were established to measure soil CO_2 efflux in dryland and rice field, respectively. We digged a trench of 30cm deep around every plot in dryland and installed PVC panel to a depth of 30cm in the soil around each plot in rice field with the intention of preventing roots near the plots from influencing the measurements of heterotrophic soil respiration. The local agricultural practices including water and fertilizer managements were followed in the croplands and in the experimental bare plots. All fields were ploughed to about 15-20 cm deep by machine. The dryland was fertilized with 40 kg N/ha, 90 kg P_2O_5/ha and 15 kg K_2O/ha surface-applied before sowing. There was no factitious irrigation practice during the soybean growing season. The rice field was fertilized three times. The first fertilization (23 kg N/ha, 50 kg P_2O_5/ha and 45 kg K_2O/ha) was surface-applied before transplanting. The second (26 kg N/ha) and the third (23 kg N/ha and 15 kg K_2O/ha) fertilization were provided by top dressing on 27 May and 26 July, respectively. The rice was continuously flooded with 4-8 cm of water until late September.

Soil heterotrophic respiration was measured using a static opaque chamber-based technique. The detailed information please see the reference (Hao *et al.* 2006). Concentrations of CO_2 were analyzed in the laboratory using a gas chromatograph equipped with a flame ionization detector (Wang and Wang 2003).

Statistics

Statistical analysis was done with SPSS. A paired t-test was applied to test the effect of land use change on soil heterotrophic respiration rates on the time series. The Pearson Correlation was performed to analyse correlations between temperatures and soil respiration rates, and Partial Correlation was performed to analyse correlations between water tables/soil water contents and soil respiration rates. In all analysis where $p<0.05$, the compare and correlate tests were considered statistically significant.

We adopt the following exponential model to analyse the relationship between temperature and soil heterotrophic respiration rate (Raich and Potter 1995): $y = ae^{bt}$, where y is soil heterotrophic respiration rate, t is soil temperature, *a* is soil heterotrophic respiration rate when t is zero, *b* is temperature coefficient. Q_{10} was calculated by the following equation (Luo *et al.* 2001): $Q_{10} = e^{10b}$.

Results

The seasonal variations of heterotrophic soil respiration

The seasonal curves of heterotrophic soil respiration from *C. lasiocarpa* marsh, *D. angustifolia* marsh and dryland were similar, and presented as a single peak. Maximum rates occurred in summer and the highest values were 714.27±51.17, 423.73±18.31 and 407.92±54.62 mg CO_2/m^2/h, respectively. The temporal changes of heterotrophic respiration from rice field also exhibited as a single peak, but the maximum value delayed to September, 466.92±54.47 mg CO_2/m^2/h. The minimal rates of heterotrophic respiration appeared in winter.

The C losses with heterotrophic soil respiration in *C. lasiocarpa* marsh, *D. angustifolia* marsh, dryland and rice field were 3.14±0.45, 4.81±0.68, 2.85±0.38 and 2.18±0.31 t C/ha/a in 2004, respectively. Marshland conversion to farmland resulted in the decrease of soil organic carbon decomposition. The reason for this may be related with the changes of some factors owing to marshland reclamation, such as the changes of micro-climate and soil underground process (the proportional rate of biomass between aboveground and underground, and the change of microbial flora, etc.), the removal of residues, the decrease of soil organic content and the reduction of soil carbon input (Larionova *et al.* 1998). Meanwhile, the variations of soil physical properties (soil porosity and aggregate structure, etc.) caused by tillage would also affect soil CO_2 efflux (Trumbmore *et al.* 1995).

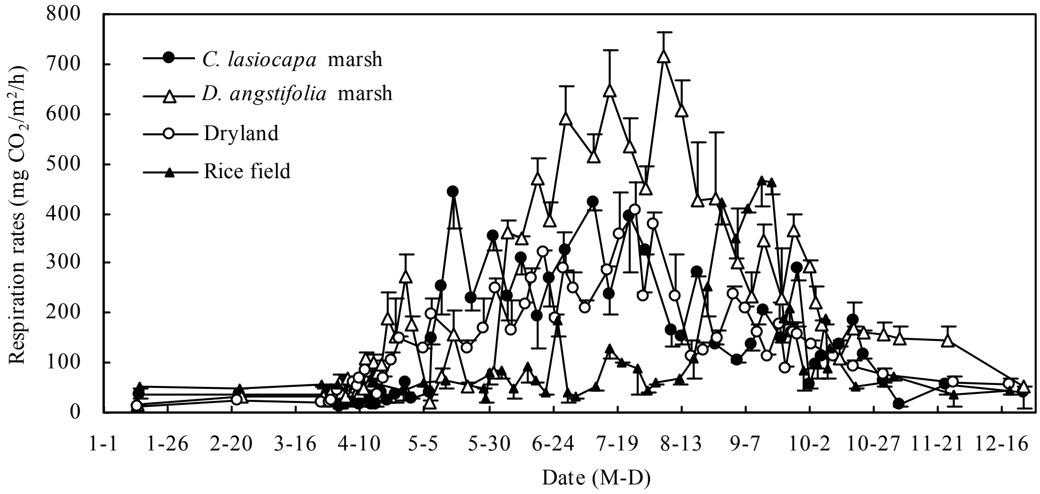

Figure 1. The seasonal changes of heterotrophic soil respiration from *C. lasiocarpa* marsh, *D. angustifolia* marsh, dryland and rice field.

Effects of soil temperature on heterotrophic soil respiration derived from soil decomposition
Heterotrophic soil respiration rates of *C. lasiocarpa* marsh, *D. angustifolia* marsh and dryland were remarkably correlated with soil surface temperatures ($p<0.001$), but the correlation between them in rice field was not significant. Heterotrophic respiration increased with the increase of temperature, showing an exponential correlation (Figure 2).

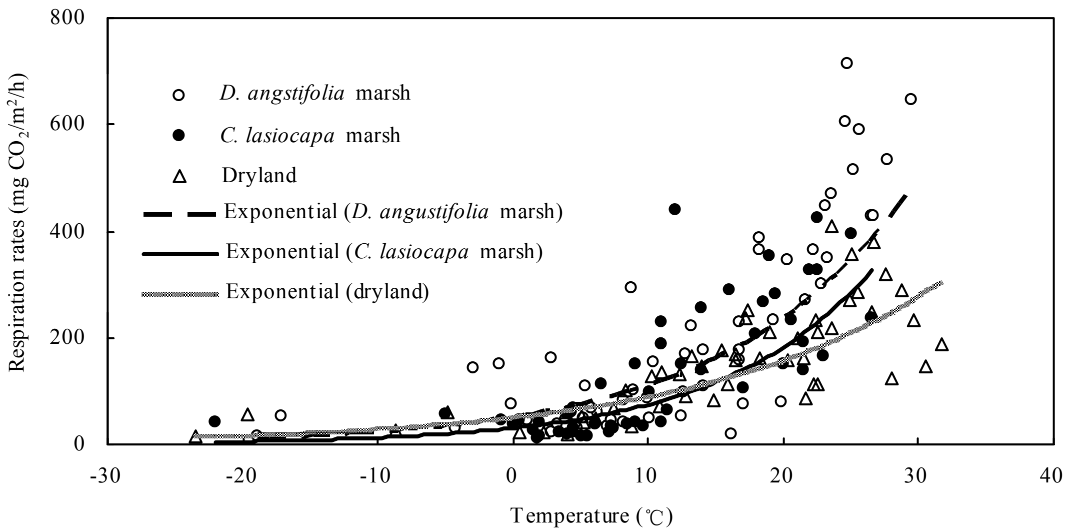

Figure 2. The relationships between heterotrophic soil respiration and soil temperature.

The Q_{10} values were 2.1, 2.5 and 1.8 in *D. angustifolia* marsh, *C. lasiocarpa* marsh and dryland, respectively. Q_{10} in *D. angustifolia* marsh was lower than that in *C. lasiocarpa* marsh, which is consistent with the result of Sommerkorn *et al.* (2008), they found Q_{10} values at wet sites were higher than any Q_{10} values at drier sites. Q_{10} in dryland was lower than that in marshlands, which was related to the low nutrition in the dryland soil because the response of heterotrophic soil respiration to temperature was mainly regulated by the quantity and quality of soil substrate (Huang *et al.* 2002).

Effects of soil moisture on heterotrophic soil respiration derived from soil decomposition
Based on the fact that there was a close correlation between soil moisture and soil temperature, Partial Correlations was adopted to analyse the correlativity between soil moisture and heterotrophic respiration in order to eliminate the effect of soil temperature. Results showed that water levels above the soil surface was

significantly negative with heterotrophic respiration in *D. angustifolia* marsh, *C. lasiocarpa* marsh and rice field, while soil volumetric water content was remarkably positive with heterotrophic respiration in the dryland. The relationships between heterotrophic respiration and soil moisture were expressed by quadratic equations in these four land uses (Table 2), which is consistent with the results from subtropical planted forest (Wang *et al.* 2008).

Table 2. The relationships between heterotrophic soil respiration and soil moisture.

Land types	Fitting equation	R^2
C. lasiocarpa marsh	$y= 0.83\ w^2 -23.80w +255.03$	0.34**
D. angustifolia marsh	$y= 41.03w^2 - 457.37w + 1292.3$	0.29**
Rice field	$y= 3.96w^2 - 40.29w + 145.28$	0.28**
Dryland	$y= 0.16\mathrm{m}^2 - 3.54\mathrm{m}+ 202.5$	0.23**

Where the w is the water level above the soil surface in marshlands and rice field (cm), m is the soil volume water content (%).

Conclusion

The seasonal variations of heterotrophic soil respiration from *C. lasiocarpa* marsh and *D. angustifolia* marsh presented as a single peak. Maximum rates occurred in summer and minimum values occurred in winter. The seasonal curve of heterotrophic soil respiration from dryland was similar with which from marshlands, while the peak value delayed to autumn in rice field. Heterotrophic respiration was much higher from *D. angustifolia* marsh than from *C. lasiocarpa* marsh, and the position of water table was the primary factor controlling heterotrophic respiration at the microsites in wetland. Heterotrophic respiration decreased owing to the conversion from marshland to farmland, and the decrease of soil organic carbon was the main reason. Heterotrophic respiration was exponentail correlated with soil temperature in *D. angustifolia* marsh, *C. lasiocarpa* marsh and the dryland, and Q_{10} value was higher in dryland than that in marshland. Water levels above the soil surface was significantly negative with heterotrophic respiration in *D. angustifolia* marsh, *C. lasiocarpa* marsh and rice field, while soil volumetric water content was remarkably positive with heterotrophic respiration in the dryland. The relationship between heterotrophic respiration and soil moisture was expressed by quadratic equations in these four land uses.

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