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Impact of Soil Temperature and Moisture on Soil Respiration under Different Cropping Patterns in Arid Oasis Area

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Abstract
A dynamic chamber method was used to measure soil respiration under four intercropping patterns and five monocropping patterns from April to September, 2009 and 2010. Soil temperature and moisture were measured to analyze correlations to soil respiration. Q_{10} values varied from 1.23 to 2.18, with minimum value for sole wheat and maximum value for maize//pea; optimum moisture for soil respiration ranging from 0.13 to 0.21m^3m^{-3}. Soil respiration of summer harvesting crops (wheat, rape and pea) was more sensitive to moisture while that of autumn harvesting crops (maize and Soyabean) was more to temperature. Ratios of biomass and yield to seasonal CO_2 fluxes for sole wheat were 32.6-40.1 kg/kg and 13.2-14.5 kg/kg, respectively, showing wheat was the crop that emitted less CO_2 but had good productivity. It was concluded that wheat//maize was recommended cropping pattern considering both lower CO_2 fluxes and higher production.

Key words: CO_2 flux, environmental factors, yield and biomass, Q_{10} value

Introduction

Soil respiration (Rs) represents an important CO_2 emission from terrestrial ecosystems to the atmosphere (*James et al*., 2004), small changes may have a large effect on CO_2 concentration in the atmosphere (Schlesinger and Andrews, 2000). Rs contains all CO_2 fluxes originating from rhizosphere, roots and soil organic matter decomposition, driven by many environmental factors such as soil temperature, air temperature, moisture and precipitation etc. (Luo and Zhou, 2006). Among these factors, soil temperature exerts strong impact on Rs (Xu and Qi, 2001), temperature sensitivity of Rs has been given considerable attention in the research of global carbon cycle (Lenton and Huntingford, 2003). An exponential relationship between Rs and temperature was first developed by van't Hoff (1898) (Raich and Schlesinger, 1992) and modified power relationships of functions by Arrhenius (1889) have also been used (Howard and Howard, 1979), goodness of fit of various temperature and respiration relationships was examined by Lloyd and Taylor (1994). There is no consensus on relationships between soil respiration and moisture across studies (Luo and Zhou, 2006).

Agroecosystems share an essential part of global carbon cycle ecosystems. Humans have significantly altered global carbon fluxes by changing land use (Paul *et* *al*., 2005). Land management could be used to increase soil carbon and thereby reduce the CO_2 concentration in the atmosphere (Post *et al*., 2004). Different cropping systems with various root activity and rhizosphere conditions may result in different emissions of CO_2 fluxes. Microbial biomass carbon contents in monoculture soil were generally lower than those in the soil from rotation systems (Gajda and Matryniuk, 2005). Previous studies have quantified impacts of land use on carbon cycles (Buyanovsky and Wagner, 1998), carbon in agroecosystem is lost directly through grain harvest and straw combustion. Under most cropping regimes, land fallowing often results in warmer soils and speeds soil respiration (Lal *et al*., 1998). Increases in soil respiration in response to soil warming were greatest in surface soil, different cropping patterns affect soil respiration directly by influencing temperature and moisture of top soils. Hardly had relative studies been conducted in oasis irrigation regions of Northwest China, this restricts our capability to adequately predict the impacts of cropping system changes on Rs in these areas.

The objectives of the experiment were (1) to estimate the lowest CO_2 emitting patterns, (2) to predict seasonal CO_2 fluxes under different patterns during growth period and (3) to quantify impacts of soil temperature and moisture on soil respiration.

Materials and methods

Measurements were carried out at Wuwei Experimental Station, Gansu Agricultural University. Study site is situated at Pinyuan village, Wuwei city, Gansu province (37°96'N, 102°64'E) at an altitude of 1506 m msl. Annual mean air temperature and annual precipitation are 7.2°C and 156 mm, respectively. The frost-free period is 156 days and evaporation capacity is 2400 mm. The region is classified as arid with a continental climate; soil is identified as thick irrigated desert soil. Experiment was conducted in 2009 and 2010 in the same field. Experiment was a randomized block design with three replicates. Five monocropping treatments [i.e., sole wheat (SW) (*Triticum aestivum* Linn.), sole maize (SM) (*Zea mays* L.), sole pea (SP) (*Pisum sativum* Linn.), sole rape (SR) (*Brassia campestris* L.) and sole Soyabean (SS) (*Glycine max*)] and four intercropping treatments [i.e., wheat//maize (W//M), maize//pea (M//P), maize//rape (M//R) and wheat//Soyabean (W//S)] were designed. Two rows of maize were grown in alternating 1.6 m wide strips with six rows of wheat in W//M treatment, with six rows of rape in M//R treatment and with four rows of pea in M//P treatment, respectively. And in W//S treatment, one strip consisted of six rows of wheat and four rows of Soyabean. Three strips comprise a plot and thus each plot area was 3×1.6 m×10 m, giving a plot area of 48 m^2. Maize was applied film mulching to make crop tolerable to low temperature at the beginning of growth period; N and P fertilizers were evenly broadcasted on the surfaces and incorporated into 25 cm depth of top soil prior to sowing, application amounts are given in table 1, plots were irrigated three to five times to keep crops from water stress. 20 crop plants were sampled from each plot at maturity and were oven dried at 65°C to constant weight to examine crop biomass; yield was measured based on a practical grain yield from each plot.

Soil respiration (Rs) was measured

by CFX-2 systems (Soil CO_2 Flux Systems (CFX-2), PP Systems, Hitchin, UK) using an infrared gas analyzer inside. The systems were with a proprietary respiration chamber (height 12 cm, diameter 20 cm). We removed the leaves and litters from soil surface, and also cut the film on maize strips a circle hole of similar diameter to release CO_2 stored the day before measurements, chamber was pushed gently into the surface about 2 cm depth, each point was taken five values and each plot measured six times from 8:00 to 20:00. Seasonal measurements were taken at 20-25 days interval, soil cores were collected by a 5 cm-diameter hand auger and three intact subsamples were saved for bulk density measurements. Soil cores were oven dried at 105°C to constant weight to calculate volumetric water contents (WC) by multiplying soil bulk density. Soil temperature (Ts) was measured using soil thermometers (Wuqiang Regong Meter Plant, Hebei, China), values in intercropping strips were determined with both crop species, thus two rows of values about each crop species were taken. Rs, WC and Ts values in intercropping were averaged into integral values to represent the whole plot.

Here we used an exponential equation as originally illustrated by van't Hoff (Sangha *et al*., 2007). The exponential equation to calculate the temperature sensitivity was $Rs = a \times e^{bTs}$ (1). Where, *Rs* was soil respiration, *Ts* was soil temperature (°C), *a* was the soil respiration rate at 0°C, *b* was a temperature response coefficient.

Observed relationships between soil respiration and moisture in filed conditions displayed widely differing forms (Luo and Zhou, 2006). In this study, a quadratic equation was considered as a better fitted function. The soil respiration to moisture could be described by $Rs = a \times WC + b \times WC^2$ (2). Where, *Rs* was soil respiration, *WC* was volumetric soil water content (m^3m^{-3}), *a* and *b* were Rs dependent coefficients. It was suggested that there were two WCs when Rs was theoretically equal to zero: (1) when WC was 0, Rs declined to 0 and (2) when WC was equal to a/b, the Rs, theoretically, became zero.

We adopted an exponential function in combination with a quadratic moisture function (Zimmermann *et al*., 2009), which was generally used to describe soil temperature and moisture interactive impacts on Rs: $Rs = a \times e^{bTs} \times \left(c \times WC + d \times WC^2\right)$ (3). Where, *Rs* was soil respiration, *Ts* was soil temperature (°C),*WC* was volumetric soil water content (m^3m^{-3}), *a* was soil respiration rate at 0°C, *b* was temperature response coefficient, *c* and *d* were moisture response constants; $Q_{10(\text{WC-independent})}$, which was defined as e^{10b}, could be calculated under a constant moisture condition; equation (3) also assumed an optimum moisture which allowed maximal activity in Rs.

Ratios of yield, biomass to seasonal CO_2 fluxes were analyzed for ANOVA to compare various treatments; functions were fitted to measured values of *Rs* by means of minimizing the least square regressions via the Levenberg-Marquardt algorithm using SPSS Statistics 17.0 (SPSS Inc., Chicago, USA).

Results and discussion

Soil respiration (Rs) was significantly correlated with soil moisture and soil temperature at 5 cm depth (Chen *et al*., 2009; Deng *et al*., 2009; Liu *et al*., 2009); in this study, we took Ts and WC at 5 cm depth (expressed as 5 cm Ts and 5 cm WC) as the main factors that influenced Rs. Mean Rs of sole Soyabean was 0.282 g $CO_2/m^2/hr$, and that of sole pea 0.297 $CO_2/m^2/hr$, which were lower than those of sole wheat (0.343 $CO_2/m^2/hr$) and sole maize (0.913 $CO_2/m^2/hr$), showing Rs of leguminous crops was relatively lower than that of gramineous crops. Mean Rs of W//S and M//P were 0.271 and 0.538 $CO_2/m^2/hr$, respectively, lower than that of W//M (0.581 $CO_2/m^2/hr$). Thus intercropping with the leguminous crops gave rise to relatively lower Rs (Fig. 1).

Correlation coefficients R^2 were in the range of 0.124 to 0.417 at $P<0.05$ across all treatments (Tab.2). The response of Rs to change in temperature was smallest in sole wheat ($R^2=0.124$ at $P<0.05$) where the minimum and maximum Rs were 0.125 and 0.925 g $CO_2/m^2/hr$, respectively, for a temperature range of 7.8-37.8°C and the second smallest was in SR treatment ($R_2=0.156$ at $P<0.05$) in which the Rs distributed in 0.044-0.655 g $CO_2/m^2/hr$ for a temperature range of 9.8-37.2°C, and the third was the SP treatment ($R^2=0.279$ at $P<0.05$). The phenomenon indicated that summer harvesting crops might emit less CO_2 because crops were of shorter growth period and were sown earlier in low temperature season. Response of Rs to change in temperature was greatest in sole maize (SM) treatment whose growth period was more than 150 days. In SM treatment, the Rs was in the range of 0.143-2.174 g $CO_2/m^2/hr$ and the soil temperature was within 10.8-35.1°C, similar to the results of Han *et al.* (2009). The maximum Rs rate of maize treatments with their Q_{10}s between 1.88 and 2.18, which were within Q_{10}s from 1.90 to 2.88 measured by Ding *et al.* (2006), Q_{10}s of maize was significantly greater than that of other crops, mulching for maize caused higher soil temperature in growth stage, indicating a larger turnover of microbial biomass in the soil (Koçyiğit, 2006). Autumn harvesting crops gave a closer relationship of Rs to Ts than summer harvesting crops, suggesting a stronger dependence of Rs on soil temperature for autumn harvesting crops. Q_{10} of SW treatment (1.23, Tab. 2) was smallest among these nine treatments, showing Rs of wheat increased slower with the temperature increasing.

Figure 2 was plotted with means of Rs calculated by averaging diurnal Rs values against volumetric soil water contents at 5cm depth. Soil moisture contents for SW treatment varied between 0.109 and 0.219 m^3m^{-3}, SM treatment were between 0.114 and 0.320 m^3m^{-3}, for SR treatment between 0.110 and 0.196 m^3m^{-3}, for SP treatment between 0.119 and 0.231 m^3m^{-3}, and for SS treatment from 0.122 to 0.269 m^3m^{-3}. SM treatment caused large variations of WCs mainly because mulching completely prevented soil evaporation, and made the largest Rs value (1.711 $CO_2/m^2/hr$) occur. There were comparably large variations in R^2 coefficients (0.051-0.672) among different treatments, demonstrating various dependences of Rs on WCs; A study on the wheat plots showed that soil respiration was significantly correlated with soil moisture but not with temperature (Jong *et al.*, 1974), we observed a similar trend that the sensitivity of Rs to WC for summer harvesting crops, especially wheat; based on calculated fit functions after equation (2), optimum WCs for all treatments were from 0.132 to 0.206 m^3m^{-3} (Tab. 3), of which optimum WCs for SM and SS were 40.48-56.50% higher than those of SW, SR and SP, also indicating that Rs sensitivity to WC for

Table 1. Basical plant cultivation systems for each crop.

Crop	Sowing	Harvest	Seeding rate (kg/ha)	Density* (plant/m^2)	Spacing row (cm)	Variety	Fertil. (kg/ha)	
							N	P
Wheat	20th Mar.	20th Jul.	412.5	743.35	12	Yongliang No.4	225	150
Maize	20th Apr.	20th Sep.	55.0	7.14	40	Wuke No.2	300	225
Rape	25th Mar.	25th Jun.	37.5	35.15	12	Haoyou No.11	45	75
Pea	10th Apr.	1st Jul.	225	52.75	20	MZ-1	185	135
Soyabean	15th Apr.	10th Sep.	112.5	14.72	20	Zhonghuang No.4	185	135

*Plant density for each crop was an average value taken by nine exampling lots in each plot.

Table 2. Regression analysis for exponential relationship ($Rs=ae^{k*Ts}$) between Rs and 5 cm Ts for various treatments.

Treatment	a	k	Q_{10}	R^2
Treatments = SW	0.119	0.021	1.23	0.124
Treatments = SM	0.141	0.072	2.14	0.320
Treatments = SR	0.151	0.026	1.30	0.156
Treatments = SP	0.113	0.037	1.45	0.279
Treatments = SS	0.072	0.058	1.79	0.417
Treatments = W//M	0.124	0.063	1.88	0.329
Treatments = W//S	0.083	0.049	1.63	0.269
Treatments = M//R	0.107	0.066	1.93	0.357
Treatments = M//P	0.075	0.078	2.18	0.359

Table 3. Regression analysis for quadratic relationship ($Rs = a^*WC+b^*WC^2$) between Rs and 5 cm WC for various treatments.

Treatment	a	b	Opt.WC/m^{3}m^{-3}	R^2
Treatments = SW	5.90	-22.41	0.132	0.672
Treatments = SM	10.03	-24.49	0.205	0.165
Treatments = SR	4.38	-15.43	0.142	0.213
Treatments = SP	4.51	-15.47	0.146	0.187
Treatments = SS	2.28	-6.99	0.206	0.151
Treatments = W//M	6.82	-18.98	0.180	0.082
Treatments = W//S	2.85	-7.11	0.200	0.051
Treatments = M//R	6.90	-20.45	0.169	0.116
Treatments = M//P	5.85	-15.32	0.191	0.053

Table 4. Calculated equation parameters for the fit functions using an exponential fit in combination with a quadratic soil moisture function with 5 cm water contents of Rs=0 and the corresponding Q_{10} values as calculated keeping WC constant.

Treatments	Calculated better fit parameters	Q_{10} (WC-independent)	WC of Rs=0 m^{3}m^{-3}	R^2
Treatments = SW	$Rs=0.935^*exp(0.005^*Ts)^*(5.687^*WC-21.664^*WC^2$	1.051	0.263	0.680
Treatments = SM	$Rs=0.189^*exp(0.086^*Ts)^*(7.725^*WC-18.971^*WC^2$	2.363	0.407	0.573
Treatments = SR	$Rs=0.113^*exp(0.084^*Ts)^*(3.396^*WC-5.329^*WC^2$	2.316	0.637	0.456
Treatments = SP	$Rs=0.384^*exp(0.006^*Ts)^*(10.026^*WC-34.128^*WC^2$	1.062	0.294	0.193
Treatments = SS	$Rs=0.359^*exp(0.033^*Ts)^*(3.915^*WC-9.431^*WC^2$	1.391	0.415	0.378
Treatments = W//M	$Rs=0.641^*exp(0.051^*Ts)^*(3.263^*WC-8.814^*WC^2$	1.665	0.370	0.209
Treatments = W//S	$Rs=0.370^*exp(0.030^*Ts)^*(4.054^*WC-10.296^*WC^2$	1.350	0.394	0.048
Treatments = M//R	$Rs=0.220^*exp(0.092^*Ts)^*(3.388^*WC-9.303^*WC^2$	2.509	0.364	0.459
Treatments = M//P	$Rs=0.164^*exp(0.082^*Ts)^*(4.534^*WC-9.513^*WC^2$	2.270	0.477	0.207

Table 5. Seasonal CO_2 fluxes within the growth periods (days for each cropping pattern as estimated by substitutions of seasonal mean Ts and WC into equation 3 and their corresponding crop biomass and yield (kg/ha) produced per kg CO_2 flux by making biomass (kg/ha) and yield (kg/ha) separately divided by seasonal CO_2 flux (kg/ha/period).

Treatments	**Growth period (days)**	**Biomass (kg/ha)**		**Yield (kg/ha)**		**Seasonal CO_2 flux (kg/ha/period)**		**Biomass/CO_2 flux (kg/kg)**		**Yield/CO_2 flux (kg/kg)**	
		2009	**2010**	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**
Treatments = SW	122	15046	18169	6089	6551	461.1	452.6	32.6±2.6a	40.1±4.0a	13.2±1.0a	14.5±1.1a
Treatments = SM	153	29448	27532	12677	11854	1553.3	1368.6	19.0±2.3e	20.1±0.5ef	8.2±0.9d	8.7±0.1c
Treatments = SR	93	3878	4192	1391	1406	301.2	240.1	12.9±1.5f	17.5±0.1f	4.6±0.4e	5.9±0.2d
Treatments = SP	82	7474	7340	2901	2850	261.5	267.7	28.6±2.8b	27.4±1.5c	11.1±1.0b	10.6±0.4b
Treatments = SS	148	11187	11255	4245	4262	436.2	404.6	25.6±2.9bc	27.8±1.1c	9.7±1.3bcd	10.5±0.3b
Treatments = W//M	153	19703	21944	8458	9418	922.8	884.0	21.4±0.1de	24.8±1.7cd	9.2±0.2cd	10.7±0.6b
Treatments = W//S	148	10599	14189	4484	6026	428.6	412.2	24.7±3.3bcd	34.4±1.2b	10.5±1.4bc	14.6±0.4a
Treatments = M//R	148	16456	17254	7052	6640	837.4	765.1	19.7±1.1e	22.6±3.1de	8.4±0.3d	8.7±1.3c
Treatments = M//P	148	17493	19293	7309	7576	801.3	791.5	21.8±2.3cde	24.4±0.9cd	9.1±0.8cd	9.6±0.8bc

Note: different letters indicate significant differences at $P<0.05$

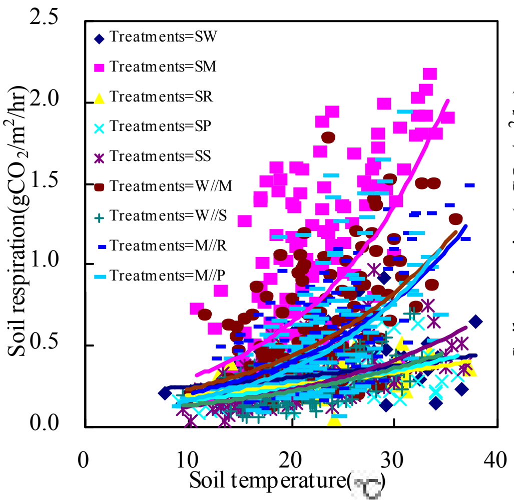

Figure 1. Soil respiration response to 5cm Ts for mono- and inter-cropping treatments

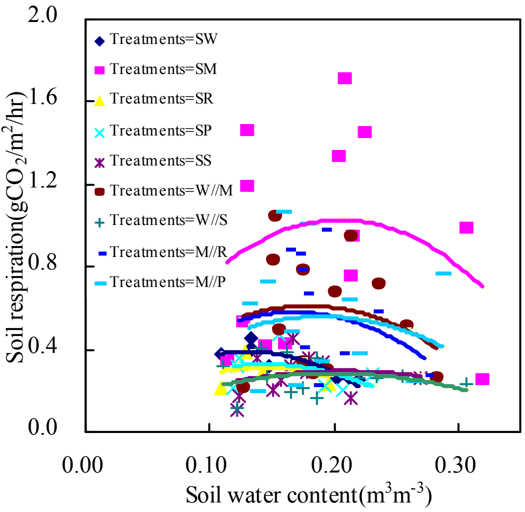

Figure 2. Soil respiration response to 5cm WC for mono- and inter-cropping treatments

summer harvesting crops was stronger.

To clearly quantify dependence of Rs on WC from different treatments, we calculated Q_{10} values keeping WCs constant [$Q_{10\ (\text{WC-independent})}$]; WCs when Rs was theoretically 0 [$WC_{\ (Rs=0)}$] were also calculated keeping soil temperature constant (Tab. 4). There were also studies giving a large range of Rs for rape from 0.121 to 1.586 g/m^2/hr (Zhang *et al.*, 2007), oilseed rape was also found to stimulate microbial activities (Dilly *et al.*, 2002), $Q_{10\ (\text{WC-independent})}$ and WCs $_{(Rs=0)}$ of sole rape (SR) treatment both enhanced compared to Q_{10} and WCs calculated by equation (1) and equation (2), respectively, indicating a possibly complicated dependence of Rs on WC and Ts for rape. Correlation coefficients

R^2 between model equation and measured values in table 4 were between 0.048 and 0.680, giving palpable differences among different treatments. But, except W//S treatments, correlation coefficients R^2 for other treatments enhanced when multi-factors (i.e., WC and Ts) were simultaneously considered. It was suggested that there might exist a positive correlation between $Q_{10\ (\text{WC-independent})}$ and WC $_{(\text{Rs}=0)}$, the greater WC $_{(\text{Rs}=0)}$ was, the higher $Q_{10\ (\text{WC-independent})}$ might be. In intercropping patterns, W//M and W//S were the suggestively lower CO_2 emission cropping patterns with lower $Q_{10\ (\text{WC-independent})}$ values. While M//P treatment was a relatively higher CO_2 emission cropping pattern with high $Q_{10\ (\text{WC-independent})}$ value (2.18).

We expressed seasonal CO_2 flux as kg CO_2/ha/period to represent total soil respiration fluxes during growth period for each crop. We calculated ratios of biomass and yield to CO_2 flux (kg/kg), respectively, to express efficiency of CO_2 flux productivity (Tab. 5). SM and W//M treatments emitted the greatest seasonal CO_2 fluxes in 2009 (1553.3 and 922.8 kg/ha/period) and 2010 (1368.6 and 884.0 kg/ha/period), respectively, while the highest biomass and yield were also produced. SR and SP treatments yielded the least productions and seasonal CO_2 fluxes, showing a positive correlation between crop productivity and seasonal CO_2 flux. However, there existed significant differences among ratios of biomass and yield to CO_2 fluxes for each treatment. Wheat was definitely the most environment-friendly crop among all crops since biomass per CO_2 flux and yield per CO_2 flux were 32.6±2.6 and 13.2±1.0 kg/kg in 2009 and 40.1±4.0 and 14.5±1.1 kg/kg in 2010, respectively, which were the greatest values among the treatments. W//S treatment wasn't a recommended cropping pattern for its annual fluctuation of crop productivity. W//M and M//P treatments were highly approved by authors as they could yield more crop productivity with relatively lower CO_2 flux, especially for W//M treatment.

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