Comparison of soil carbon dioxide emission between controlled and random traffic under conservation tillage

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Abstract: Conservation tillage is proven to be a useful agricultural practice for reducing the concentration of CO_2 released to the atmosphere, but there is currently only limited information regarding the influences of controlled traffic on soil CO_2 fluxes. Therefore, this study investigated the effects of controlled traffic on soil CO_2 flux and on fuel consumption in winter wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) croplands of northern China. CO_2 samples were collected from various compacted areas in the fields, including the crop zone, the inter-row zone and the traffic zone. CO_2 flux from the soil surface was measured with a GXH-3010E1 CO_2 infrared analyzer during the crop grain filling stage. CO_2 fluxes were considerably larger for controlled traffic field (95.04±6.79) g/(m^2 • d) than that for random traffic field (50.91 ±7.57) g/(m^2 • d) in the crop zone, but there were no significant differences between random and controlled traffic fields in the inter-row zone. In contrast, in the traffic zone, all fluxes were lower than those in the other areas. Total CO_2 fluxes were not significantly different between controlled traffic and random traffic fields. Controlled traffic can reduce fuel consumption by 9.7 L/hm^2 compared to random traffic, which implies that it can also reduce the total annual amount of CO_2 released from agricultural activities.

Keywords: conservation tillage, controlled traffic, random traffic, CO_2 flux, fuel consumption
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1 Introduction

With the increase in mechanization, and especially with the use of heavy agricultural machines now widely adopted in farmlands, soil compaction due to machinery traffic has become increasingly severe. Compaction is a well-recognized problem in many parts of the world and has adverse effects on a series of key soil properties. Soil in the 0.05–0.10 m layer under wheel tracks has been reported to have a significantly higher penetrometer resistance and bulk density and a lower air-filled porosity comparing to those measured between wheel tracks in the second cropping year[1]. The soil hydraulic properties can also be influenced by compaction. Zhang et al.[2] showed that saturated hydraulic conductivity was significantly reduced by high compaction in the loess plateau of China. High crop yield has been associated with low soil compaction[3]. Soil compaction also has negative effects on the overall environment. For example, it can reduce water infiltration and increase erosion.

Soil compaction effects can last for years and these may not be reduced by tillage or freeze-thaw cycles; however, in present-day agriculture, eliminating vehicle traffic in agricultural cropland is impossible. Therefore,

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to minimize the effects of vehicle traffic on crop production and the soil environment, other methods need to be invoked, such as reducing the amount of vehicle traffic, reducing the size of vehicles, controlling the traffic, minimizing tractive element-soil contact stress, or by subsoiling.

Controlled traffic on croplands has been advocated since the 1960s by scientists in many countries as a solution to soil compaction. Today, farmers in a number of areas (e.g., China and Australia) have adopted controlled traffic, and it has been vigorously advocated in both the USA and Europe[4]. Controlled traffic farming can avoid many of the contradictions between tillage and traffic processes[5], as wheel traffic increases soil strength while subsequent tillage reduces soil strength. Braunack and McGarry[6] found that, compared with random traffic and conventional tillage, controlled traffic tillage improves soil properties in the crop row. At the same time, the practicability and positive economic effects of a controlled traffic system have been demonstrated by large scale and enthusiastic farmer adoption in Australia[4] (Tullberg, et al., 2007). Li et al.[7], by comparing traffic and tillage effects over six years on a heavy clay vertosol, found that controlled traffic could increase plant available water capacity by 11.5% in the 0−500 mm zone.

While the effects of controlled traffic on the physical properties and erosion of soil are well documented, the effects of controlled traffic on soil CO_2 emission are less well understood. Controlled traffic may be able to increase soil C sequestration and reduce soil CO_2 emissions by maintaining appropriate soil properties. The purpose of this study was therefore to determine whether controlled traffic could decrease soil CO_2 emissions.

2 Materials and methods

2.1 Study site and experimental design

The field experiments were conducted on sand loam–textured soils located at Beijing district (39°45'N, 116°20'E). Mean annual precipitation was 568.9 mm and annual temperature was 11.5℃.

Prior to the experiment, the study area was planted to a crop rotation consisting of winter wheat and maize; the experimental area was divided into two 150 m×100 m fields (Figure 1) after the autumn of 2004. In one of the fields, traffic was controlled, while in the other, it was random. Both field sites had uniformly flat topography and conservation tillage had been used on them. The controlled traffic plot was divided into a crop zone, which was a relatively large area with a loose soil structure, and traffic lanes that were unplanted, compacted areas managed primarily for trafficability.

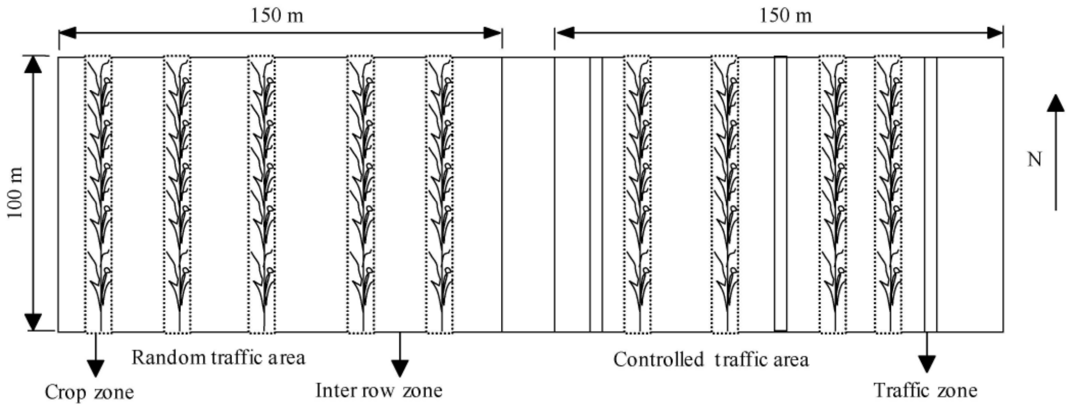

Figure 1 Layout of field experiment

2.2 Measurement of soil CO_2 emissions, soil moisture and soil temperature

The soil CO_2 fluxes were measured from different compacted area in the fields, including the crop zone, the inter-row zone and the traffic zone. CO_2 flux from the soil surface was measured during the grain filling stage with the GXH-3010E1 CO_2 infrared analyzer produced by Beijing Huayun analytical instrument institute and described by Yu and Sui[8]. The instrument was linked to a closed chamber (equipped with an electric fan for air circulation) that covered a surface area of 0.04 m^2 and had a volume of 0.024 m^3. Soil respiration was measured with an opaque closed chamber and CO_2 net emission was measured using a transparent closed chamber. The measurements were made in both the crop and the inter-row zones. The chamber was lowered over the treatment surface and its bottom support frame was inserted into the soil approximately 20 mm. CO_2 concentration was measured at 10-second intervals over a two-minute period and the readings were stored on a laptop computer. Nine samples have been collected from each treatment (N=9). All measurements were conducted in the morning (09:00−11:00), as the soil CO_2 fluxes in the morning generally well-represent the mean daily fluxes[9].

Soils (0–20 cm in depth) were sampled and weighed in four sample points per spot. After drying at 105℃, the soil samples were weighed again to determine soil water content (g/kg). Soil bulk density was also measured, six replications per site, by taking soil samples using a corer (5.2 cm in diameter and 5.5 cm in length) with a 100 cm^3 sample volume. Soil temperature was measured using thermocouples at 0, 10 and 20 cm depths at each sampling site. The controlled traffic field was divided into crop zone and traffic zone sections, and measurements of soil bulk density, soil water content and soil temperature were carried out in each zone. Root dry weight and root length density at the grain filling stage were also measured at each location. Two root samples, one for root length density and the other for root dry weight, were collected at 0–15 and 15–30 cm depths using a 3.25 cm diameter manual soil core sampler. Root length density was determined using the line intersection method[10]. Each soil subsample was immersed in a sodium Hexametaphosphate (1N) solution for 30 min, and then was wet-sieved (sieves of 0.495 and 0.125-mm mesh size) for root collection. Collected roots were randomly placed on a filter paper and the total root length (R) was determined with a transparent polycarbonate grid (1 cm × 1 cm) by counting the number of intersections between roots and the grid. The total root length was calculated as: $R = \frac{\pi AN}{2H}$, where A is the area occupied by roots over the filter paper, N is the number of intersections, and H is the total length of the grid. The root length density ($cm/cm^{3)}$ was calculated by dividing the root length by the volume (cm^{-3}) of the sampling core. Root dry weight was determined after oven drying the root samples.

2.3 Data analysis

SPSS analytical software package was used for all statistical analyses. Mean values were calculated for all measurements, and ANOVA was used to assess the effects of controlled traffic on crop yield, soil bulk density and soil CO_2 flux. In cases of significant F-values ($P<0.05$), multiple comparisons of annual mean values were made on the basis of least significant difference (LSD).

3 Results

3.1 Crop and soil measurements controlled trial

3.1.1 Crop yield

No significant difference in crop yield was found between the controlled traffic and random traffic fields; the crop yield for controlled traffic and random traffic averaged 4642 and 4909 kg/hm^2, respectively (Table 1).

Table 1 Crop yields (kg/hm^2) under controlled traffic and random traffic field

	Spikes per ha	Grains per spike	thousand-grain weight/g	Yield
Controlled traffic	3058000^a	34^a	44.64^a	4642^a
Random traffic	3531000^b	33^a	42.13^b	4909^a

Note: Mean in a column followed by the same letter were no significantly different ($P<0.05$) by Duncan's test method.

Although the traffic lane accounted for about 30% field area, there were fewer spikes per ha than for the random controlled traffic field; however, the thousand grain weight for the controlled traffic field was larger than that for the random traffic field（Table 1). These results were opposite to those presented previously[7] in which controlled traffic increased mean winter and summer grain yields by 9.4%, where the traffic lanes accounted for 20% of the field area. Therefore, controlling the proportion of traffic lanes in a field can increase crop yields by reducing traffic-induced soil compaction in the crop zone.

3.1.2 Soil bulk density

Controlled traffic had a noticeable and immediate effect on soil bulk density (Table 2) of the traffic zone, which was 9.5% and 6.8% higher than that of crop zone at 0−10 cm and 10−20 cm depth, respectively. This is consistent with the results of Paul[11] , who reported the greatest values of soil bulk density in the traffic zone from repeated traffic and least in the crop zone from lack of traffic.

Table 2 Effects of tillage treatment on soil bulk density

g • cm^{-3}

Tillage			2005	2006	2007	2008	LSD
0−10 cm	Controlled traffic	Crop zone	1.26	1.30	1.25	1.29	ns
		Traffic zone	1.38	1.38	1.45	1.47	0.06
	Random traffic		1.31	1.33	1.34	1.33	ns
	LSD		0.10	0.07	0.11	0.09	
10−20 cm	Controlled traffic	Crop zone	1.33	1.37	1.32	1.32	ns
		Traffic zone	1.42	1.44	1.48	1.56	0.12
	Random traffic		1.34	1.43	1.43	1.44	ns
	LSD		0.08	0.05	0.09	0.10	

Note: LSD is least significant difference at $P<0.05$; ns=not significant.

No significant effects of crop zone were found between controlled traffic and random traffic at surface (0−10 cm) soil. After 2005, the soil bulk density was lower in the crop zone of the CTF (controlled traffic field) compared with the RTF (random traffic field) for subsurface (10−20 cm) soil. This is consistent with the results of Braunack and McGarry[6], who reported that soil bulk density was greater in the row under RTF compared with CTF. Average soil bulk density of subsoil under RTF was increased by 5.6% comparing to that of the CTF.

Measurements made in 2005, 2006 and 2007 showed no significant differences for the traffic zone of the CTF, but by 2008, a significant increase in soil bulk density was observed. Soil bulk density had been significantly increased after three years of soil compaction.

3.2 Surface soil CO_2 flux in the field study

3.2.1 Crop zone

CO_2 emissions were significantly different at crop zone between the RTF and the CTF when measured with an opaque closed chamber. The CO_2 fluxes were considerably larger for the CTF (95.04±6.79) g/(m^2 • d) than for the RTF (50.91±7.57) g/(m^2 •d); However, the CO_2 emissions were not significantly different when the transparent closed chamber was used for measurement (Figure 2).

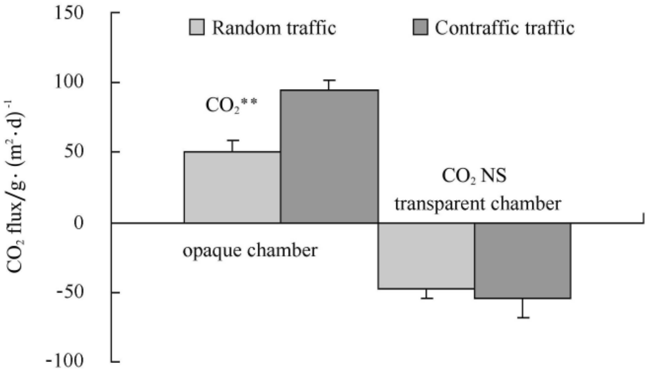

Figure 2 Effects of traffic on CO_2 flux under opaque and transparent chambers in the crop zone. Significance levels from ANOVA for CO_2 flux effect: (**) $P \leqslant 0.01$; NS not significant

Carbon dioxide is produced in soil as a result of decomposition of organic material by microorganisms and from root respiration. The differences in measurement with the transparent and opaque chambers gave an estimate of the CO_2 fixation by photosynthesis by the crop ground cover, and for that reason, the flux value was lower (Figure 2). Root length density and root dry weight can express below-ground plant biomass to some extent, root derived respiration is proportional to both above and below ground plant biomass[12,13]. At the crop zone, CTF increased root dry weight and root length density compared with the RTF (Figure 3). This may be one reason why the CTF had an increased CO_2 flux compared with the RTF.

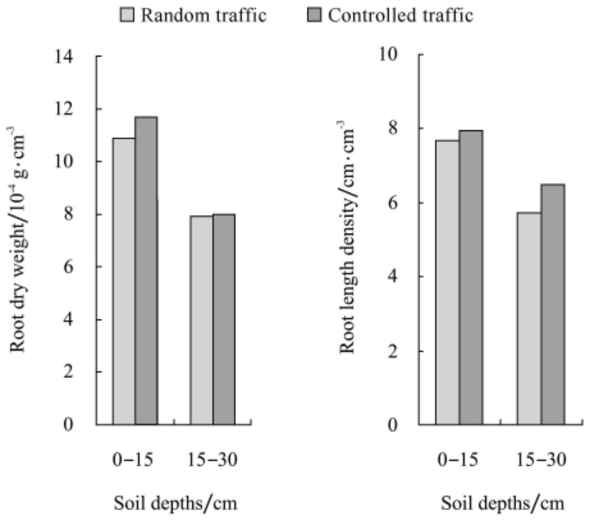

Figure 3 Root dry weight and root length density at the phonological stage of grain filling for the controlled traffic and random traffic

3.2.2 Inter-row zone

No significant differences were found between RTF and CTF in the inter-row zone for the CO_2 emission from soil respiration and root respiration; however, inter-row emissions were significantly higher than those of the traffic zones (Figure 4). These results are in agreement with those of Pengthamkeerati et al (2005), who reported that soil CO_2 release was significantly reduced with increasing soil bulk density[14].

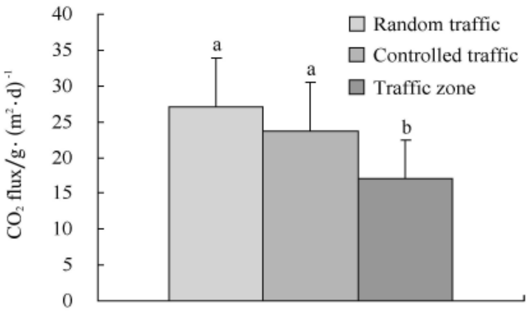

Figure 4 Soil respirations on inter row zone under random traffic and controlled traffic and traffic zone. Different lower case letter indicate significant (P<0.05) difference between inter row zone and traffic zone

As expected, soil CO_2 flux was significantly decreased in soils that experienced vehicle traffic compared to those that had no traffic. This indicates that soil compaction had a positive effect on soil CO_2 flux, due to the increased soil bulk density (Table 1). Soil bulk density can limit gas transport and limit soil aeration, which, in turn, can reduce soil microbial activity[14].

4 Discussion and conclusions

Soil CO_2 fluxes of crop zones were higher in CTF than in RTF. They were also higher in the inter-row zones than in the traffic zones, but the fluxes from inter-row zones were similar in both fields. Considering the total CO_2 flux, which comprises the crop zone and the inter-rows, it was found that there were no significant differences between CTF and RTF. However, these findings do not imply that controlled traffic cannot reduce CO_2 emissions. The most serious CO_2 emissions in agriculture come from the burning of fossil fuels on arable land[15]; controlled traffic can reduce the CO_2 fluxes through the reductions in fuel consumption.

Additional, Fuel consumption experiments conducted between CTF and RTF from 2007–2008 by our research group[16], the results indicated that the fuel consumption of operation was reduced by 9.7 L/(hm^2 • a) in a CTF (31.9±4.1) L/(hm^2 • a) compared to a RTF (41.6±4.8) L/(hm^2 • a). According to the emissions of 2.75 kg CO_2 per L fuel consumption[17], the resultant CO_2 flux is 87.7 kg/hm^2 for the CTF and 114.4 kg/hm^2 for the RTF. Therefore, if the farmers of northern China were to adopt controlled traffic production methods, a reduction in the total annual amount of CO_2 released by soil tillage of an additional 10^4 t or 2.3% could be expected, and if the conventional tillage were to be changed to controlled traffic, agricultural CO_2 release could be reduced even more.

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