NARDI FUNDULEA, ROMANIA
www.incda-fundulea.ro

ROMANIAN AGRICULTURAL RESEARCH, NO. 34, 2017
Print ISSN 1222-4227; Online ISSN 2067-5720

STRAW MULCHING CAN REALIZE SOIL/PLANTS CARBON SEQUESTRATION AND YIELD INCREASING OF *SUMMER MAIZE* IN NORTH CHINA

Changjian Ma[1,2], Xinhui Liu[1], Chengyue Bian[1],Quanru Liu[1], Quanqi Li [1,*]

[1]College of Water Conservancy and Civil Engineering, Shandong Agricultural University, Tai'an, Shandong 271018, PR China

[2]College of Water Resources and Civil Engineering, China Agricultural University, Beijing 100083, PR China

*Corresponding author. E-mail: quanqili@sdau.edu.cn; sdaumcj@163.com

ABSTRACT

North China Plain is a main grain producing area in China. It is very important for China to find a simple and low carbon method for grain production. To better understand the potential for increasing grain yield and carbon absorption, treatment effects of straw mulching on grain yield, carbon absorption in crop growth period, and soil CO_2 emission characteristics in 2012-2014 summer maize growing seasons were quantified. The experiment involved summer maize with two straw mulching rates, i.e., 0 and 0.6 kg m^{-2}. The result showed that soil respiration rate in straw mulching (M) was significantly lower than that in non-mulching (N). The carbon absorption and grain yield in M was significantly higher than that in N. In the three growing seasons, ear number, kernels per row, 1000-kernel weight, and grain yield in M were higher than that in N by 4.07%, 4.03%, 10.93%, and 20.54%, respectively. The result indicates that straw mulching has the effect of yield increasing and soil carbon sequestration in summer maize crop in North China.

Key words: soil CO_2 emission; grain yield; carbon absorption; straw mulching; summer maize.

INTRODUCTION

In recent years, the growth of population, the increase of human activities, and the development of economic and social factors lead to global climate change by rising CO_2 concentration. These changes formed a vicious spiral, gradually changed the agricultural ecological environment, reduced the output of grain (Schlenker et al., 2009) and threatened the global food security seriously. Global average temperature from 1880 to now also have risen by 0.8°C, and the number will rise for 3 to 7°C by 2100 (Allen et al., 2009).

Soil is the world's second largest organic carbon library. Soil respiration plays an important role in the global CO_2 gas exchanging and atmospheric CO_2 concentration changing (Zhang et al., 2014), especially the CO_2 amount released from the farmland soil respiration (Lin, 2001). Agricultural emission reduction potential can be more than 20% of the total natural potential, of which 90% from soil carbon. It should be attached importance.

North China Plain, as China's second largest plains, locates 32°N～40°N and 114°E～121°E, area reaches 3.2×10^5 km^2. Summer maize is one of the most important crops in China, and the plant planted in the Plain occupies 30% in areas and 50% in production of China (Zhang et al., 2013). Therefore, the summer maize grain production increasing is related to the North China even China's food security.

There is no unified conclusion about the effect of straw mulching on soil respiration rate and cumulative CO_2 emissions flux. Lenka and Lal (2013) found that CO_2 flux was increased with the increase of wheat straw quantity under the condition of N and no-N fertilizer. The opposite result appeared in another study, which showed that the cumulative soil CO_2 emission of no-tillage with residue treatment was lower than that without resident by 24% in maize-soybean farmland (Al-Kaisi et al., 2005). The influence on soil respiration rate and cumulative CO_2 emissions flux is different in different time,

Received 29 July 2015; accepted 07 February 2017. First online: February, 2017. DII 2067-5720 RAR 2017-115

place and crops straw mulching. Therefore, further research is very necessary.

Although a lot of studies were implemented in farmland carbon sequestration, the impact of straw mulching measures on summer maize yield and soil respiration rate, and correlation between influence factors is less studied. We assume that the straw mulching has the function of carbon sequestration and yield increasing of summer maize. The experiment was conducted during 2012-2014 summer maize growing seasons, and included 2 kinds of treatments (mulching and non-mulching), and in an attempt to (I) explore the change about soil CO_2 respiration and crop carbon absorption by mulching; (II) determine the effect of straw mulching on grain yield and yield components; (III) analyse the relationship between soil CO_2 respiration and environment factors, and (IV) verify if there are high-yielding and carbon sequestration effects by mulching.

MATERIAL AND METHODS

Experimental site

The study was conducted at the Experimental Station of Shandong Agricultural University (36°10″09′N, 117°09″03′E), which locates in the centre of North China Plain. In the site, average annual rainfall is 697 mm, 70% of which was concentrated from July to September in the summer maize growing season. The experiment was conducted in plots (9 m^2) divided by concrete walls (25 cm thick) that extended 1.5 m beneath the surface and 10 cm above the surface. The soil with 32.4% field water capacity in the plots was original loam incorporate. Alkaline hydrolysis nitrogen, available potassium, and available phosphorus in 0-20 cm soil were 108.1, 92.4, and 16.1 mg/kg, respectively. There was no groundwater recharge and no water loss and soil erosion.

Experimental design

In the experiment, 2 straw mulching rates were employed in summer maize growing seasons, i.e., 0.6 and 0 kg/m^2. At the summer maize 5-leaf stage, straw mulching was carried out by applying winter wheat dry straw that was chopped into 3-5 cm. The summer maize variety was "Denghai 661". Each plot was planted for five rows, row spacing was 60 cm, and plant distance was 22.2 cm. This experiment was randomised complete block design; each treatment was repeated 3 times. The rapidly available nitrogen, phosphorous, and potassium contained in chemical fertilizer were scattered on the fields at 7.5, 11.3, and 15.0 g/m^2, before rainfalls according to the weather forecast (Liu et al., 2014). The plots were planted on June 17, June 19, and June 15 in 2012, 2013, and 2014, respectively; and were harvested on October 3, October 2 and October 1, in 2012, 2013 and 2014, respectively. There was no additional irrigation or fertilization during the whole summer maize growing seasons.

Measurements

A GXH-305 Portable Gas Analyser (ADC Bioscientific Ltd., Hoddesdon, England) was used to measure the CO_2 flux together with six static chambers (15.7 cm in height and 25.0 cm in diameter) which were made of PVC pipe for gas sampling. Sunny days were selected to monitor soil respiration during 9:00-10:00 am (Davidson et al., 1998) once every 10-20 days. Before measurement, the weeds on the ground were eliminated and then the gas chamber was inserted randomly into the field without disturbing surface soil. Each monitoring was sustained for 1-2 min to guarantee the stability of airflow and accuracy of numerical value. At the same time, 10 cm soil temperature, 10 cm soil moisture content, air temperature 10 cm above the ground surface, and air humidity 10 cm above the ground surface were also measured together from every treatment.

The soil surface CO_2 flux was used to figure out the soil respiration rate, using the formula of the soil surface CO_2 flux quoted from Liu et al. (2014). The cumulative CO_2-C emissions were computed by formula from Meng et al. (2005). The amount of carbon absorption capacity in the summer maize growing seasons was calculated according to Zhao and Qin (2007). Maize grain yield and yield components were determined by harvesting uniformly grown maize plants randomly except the border rows in each plot. The rainfall data was provided by the weather station, which was closed to the Experimental Station of Shandong Agricultural University.

Statistical analysis

Microsoft Excel 2007 and Statistical Product and Service Solutions (SPSS) were used for the data processing and statistical analysis, the least-significant difference method (LSD) was used for significance test and Origin 8.0 software for drawings.

RESULTS AND DISCUSSION

Precipitation

The precipitation in 2012 and 2013 summer maize growing seasons mainly occurred in July, which differed from 2014 when mainly occurred in July and September. Both 2012 and 2014 were classified as low rain years, and 2013 as normal rain year.

Table 1. The precipitation in 2012, 2013 and 2014 summer maize growing seasons

Months / Years	June (mm)	July (mm)	August (mm)	September (mm)	October (mm)	Total rainfall (mm)
2012	16	210.5	53.4	61.6	15.7	357.2
2013	36.8	399.8	42.9	11	3.7	494.2
2014	26.3	110.2	32.9	124.7	2.8	296.9

Soil respiration rate and cumulative CO_2 emissions flux

Soil respiration rate in 2012, 2013, and 2014 summer maize growing seasons was presented in Figure 1. It's obvious that soil respiration rate was much lower in M than in N. In 2012, soil respiration rate had zigzag distribution, maximum and minimum values in N were 6.28 and 2.67 μmol m^{-2} s^{-1}, and in M were 5.44 and 1.43 μmol m^{-2} s^{-1}, respectively. Soil respiration rate in M was lower than that in N by 37.21%, 3.47%, 6.43%, 36.99% and 13.44% on 14 July, 12 August, 29 August, 18 September, and 3 October, respectively. In 2013, soil respiration rate had a single peak distribution, maximum and minimum values in N were 9.52 and 1.04 μmol m^{-2} s^{-1}, and in M were 7.22 and 0.77μmol m^{-2} s^{-1}, respectively. Soil respiration rate in M was lower than that in N by 33.42%, 8.72%, 24.22%, 15.68%, and 25.57% on 8 July, 7 August, 17 August, 12 September, and 3 October, respectively. In 2014, the variation trend in soil respiration rate was the same as in 2013, and the maximum and minimum values in N were 5.99 and 2.60 μmol m^{-2} s^{-1}, and in M were 5.37 and 2.22 μmol m^{-2} s^{-1}, respectively.

Cumulative CO_2-C emissions flux in both M and N in 3 summer maize growing seasons was presented in Figure 2. The result showed that the cumulative CO_2-C emissions flux was much lower in M than in N, and the reduction ratios in 2012, 2013, and 2014 were 28.70%, 10.86%, and 11.39%, respectively. Both in M and N, the highest cumulative CO_2-C emissions flux was found in 2013 summer maize growing season, than followed by 2014, and the lowest value was found in 2012.

The result of the experiment was similar to the research of Tanveer et al. (2013). Compared with no-till uncovered by residue, there's a certain inhibitory effect of no-till cover residue in CO_2 emissions. Researchers showed that straw mulching increased soil moisture content, the organic matter (Mupangwa et al., 2013), and soil carbon concentration under no-tillage treatments (Kahlon et al., 2013). Straw mulching can raise the temperature in low temperature period and reduce the temperature in high temperature period (Li et al., 2008). This experiment was conducted in summer maize growing season, straw mulching leaded to low soil temperature (Li et al., 2013), which affected plant root respiration and soil microbial activity, resulting in a decrease of soil respiration; however, the exact cause remains to be further studied. Otherwise, different rainfall years may cause different environmental factors and even lead to change in plant physiology characteristics. Therefore, the cumulative CO_2-C emissions flux reached its highest in 2013 and the lowest in 2012, which may be because that 2013 was a normal rain year and 2012 was a low rain year. As for 2014, its cumulative CO_2-C emissions flux was between 2012 and 2013; the reason may lie in the rainfall distribution, which had two peaks in July and September, although it was a low rain year. But the exact cause remains to be further studied.

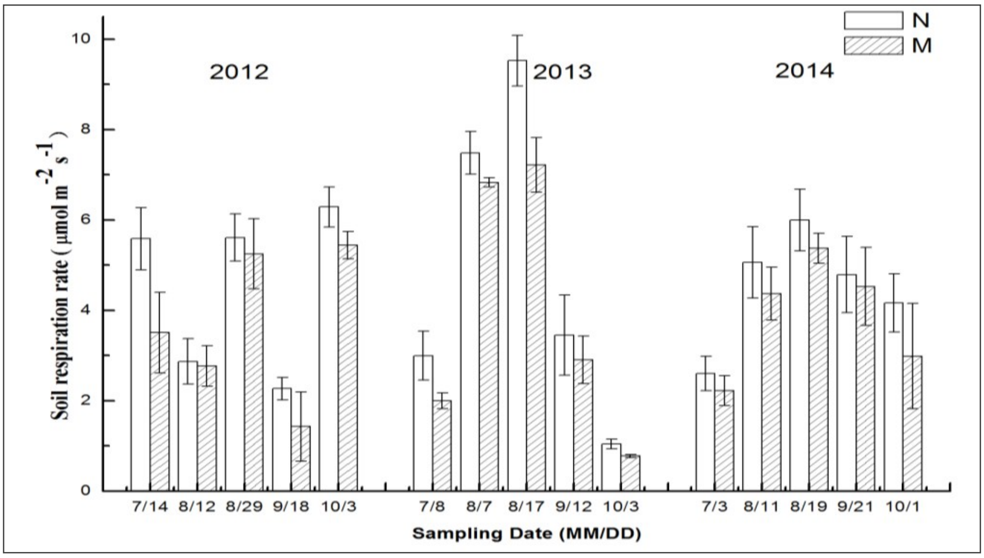

Figure 1. Soil respiration rate in mulching (M) and non-mulching (N) treatments in 2012, 2013, and 2014 summer maize growing seasons. Vertical bars represent standard error

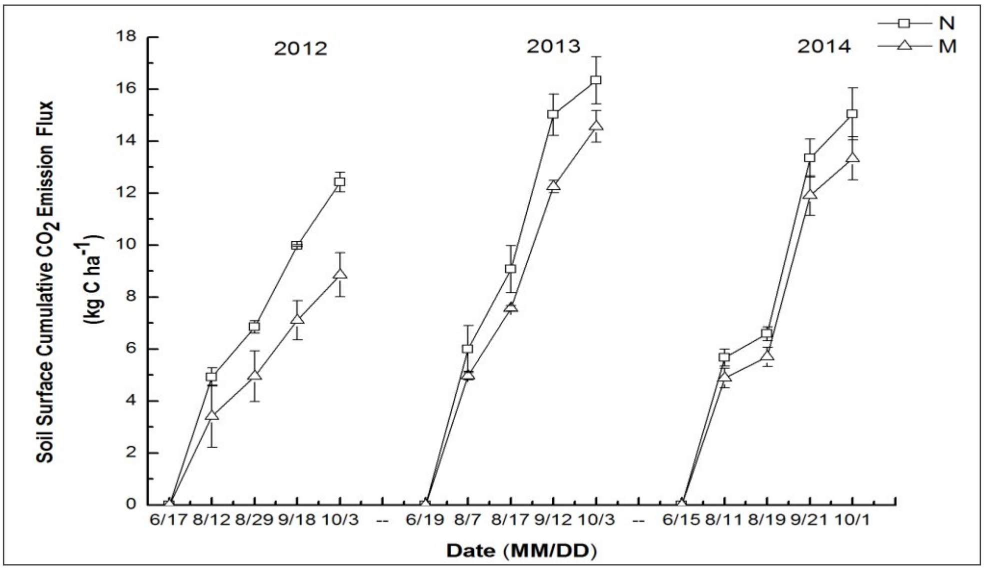

Figure 2. Cumulative CO_2 emissions flux in both mulching and Ns in 2012, 2013, and 2014 summer maize growing seasons. Vertical bars represent standard error

The correlation between soil respiration rate and other environmental factors

The correlation between soil respiration rate and environmental factors of M and N was demonstrated in Table 2. In M, significant correlation ($p<0.01$) was found between the soil respiration rate and soil temperature ($r=0.645$), as well as with air temperature ($r=0.547$) and air humidity ($r=0.631$). In N, significant correlation ($p<0.01$) was found between the soil respiration rate and soil temperature ($r=0.586$), as well as with air humidity ($r=0.632$).

Table 2. The correlation between soil respiration rate and environmental factors in both mulching and non-mulching

Environmental factors	Soil respiration rate ($\mu mol\ m^{-2}\ s^{-1}$)	Soil temperature (℃)	Soil humidity (%)	Air temperature (℃)	Air humidity (%)
Soil respiration rate ($\mu mol\ m^{-2}\ s^{-1}$)		0.645**	-0.156	0.547**	0.630**
Soil temperature (℃)	0.586**		-0.412**	0.760**	0.681**
Soil Humidity (%)	-0.012	-0.395*		-0.503**	-0.460*
Air temperature (℃)	0.337	0.887**	-0.681**		0.529**
Air humidity (%)	0.632**	0.714**	-0.480**	0.638**	

Note: ** mean statistically significant difference at p=0.01, and * mean statistically significant difference at p= 0.05. Above diagonal line is for mulch treatment, and the other side is for N.

Related studies found that a significant positive correlation exists between soil respiration and soil temperature within a certain range of soil temperature (Qin et al., 2011). The reason may be that high soil temperature can accelerate the organic matter decomposition in soil and microbial activity, thereby increasing greenhouse gases emissions in the soil. As for soil moisture, in the field crops study, it's generally not as limiting factor that affects the soil respiration rate (Sangha et al., 2007). Only in the arid areas and rainfed agricultural region, when there is a drought stress, the soil moisture content can become one of the main factors limiting soil respiration (Han et al., 2008). There was no significant correlation between soil respiration and soil humidity in this study, which was similar to previous studies by Qin et al. (2011). As for the reason, Wagai et al. (1998) found that soil respiration rate and soil moisture was significantly positively related in arid grassland of eastern Washington; however, there was significantly negative correlation between respiration and soil moisture in forest and grassland soil of Amazon (Davidson et al., 2000). In this study, the experimental site was a warm sub-humid continental monsoon climate zone, with 13℃ average annual temperature and 697 mm average annual rainfall in central north China plain, between cold and torrid zones; therefore, this may be the reason that soil respiration had nothing to do with the soil moisture. This was the same as in Florida (Fang et al., 1998). As to its mechanism, may be because soil respiration was not sensitive to soil moisture when soil moisture was in certain range, or not changing much. Only under extreme conditions, that is, when the soil moisture is more than field capacity or lower than the permanent wilting point, moisture's limiting effect would occur on soil respiration (Pangle et al., 2002). This may be because the low soil moisture will limit the root respiration and soil microbial respiration, and high soil moisture will block the soil porosity and limit the release of CO_2 by reducing the O_2 concentration in the soil (Cable et al., 2008).

Carbon absorption

Carbon absorption in M and N in 2012, 2013, and 2014 summer maize growing seasons was presented in Figure 3. The experiment indicated that carbon absorption in M was significantly higher than that in N in the three summer maize growing seasons, and the surpassing ratio were 32.68%, 23.57%, and 28.93%, respectively. Crops absorb CO_2 through photosynthesis, and the farmland ecosystem is a weak carbon sink (He et al., 2009). Research indicated that the assimilating CO_2 by terrestrial vegetation was the most safe and effective CO_2 absorption process (Li and Tang, 2006). Therefore, the objective data shows that the crops carbon sequestration should get more research and utilization.

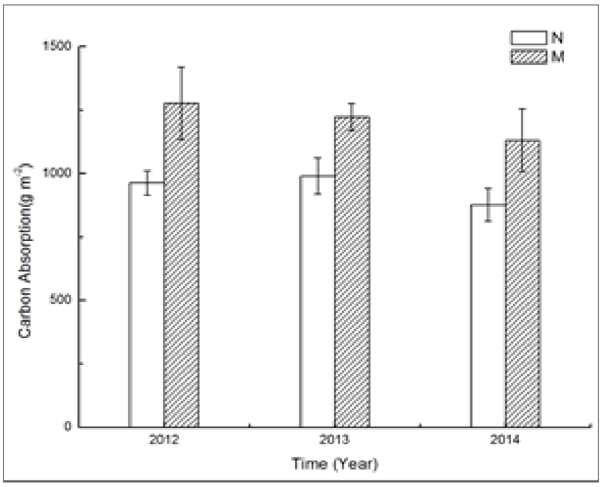

Figure 3. Carbon absorption under mulching and Ns in 2012, 2013, and 2014 summer maize growing seasons. Vertical bars represent standard error

In this study, the carbon sequestration in M was higher than that in N, which shows the straw mulching had a very positive impact on summer maize carbon sequestration and is a kind of good measures to improve the summer maize plants carbon sequestration.

Grain yield and yield components

Grain yield and yield components in M and N in 2012, 2013, and 2014 summer maize growing seasons was presented in Table 3. In 2012, there was a significant increment in both kernels per row and 1000-kernel weight in M over that in N, the rate of increment being 4.51% and 8.74%, respectively. In 2013, the result indicated that the grain yield increment in M was caused by the increment in 1000-kernel weight, and M resulted in 22.77% and 28.97% increment rate in 1000-kernel weight and grain yield as compared with that in N. In 2014, there was no significant difference between the two treatments in grain yield and yield components. From 2012 to 2014, there was no significant difference in rows per ear between M and N, and the influence of straw mulching on grain yield was caused by ear numbers, kernels per row, and the 1000-kernel weight.

Table 3. Grain yield and yield components in mulching and Ns in 2012, 2013, and 2014 summer maize growing seasons

Growing seasons	Treatments	Ear number (ears /m^{-2})	Rows per ear (rows ear^{-1})	Kernels per row (Kernels row^{-1})	1000-kernel weight (g)	Grain yield (g m^{-2})
2012	N	7.63a	15.82a	29.52b	299.82b	1043.53b
	M	7.93a	16.29a	30.85a	326.03a	1255.44a
2013	N	7.63a	16.06a	29.28a	265.30b	906.25b
	M	7.63a	16.17a	30.16a	325.70a	1168.85a
2014	N	6.85a	15.89a	20.80a	297.19a	683.08a
	M	7.44a	16.56a	21.78a	304.85a	749.37a
2012-14	N	7.37b	15.92a	26.53a	287.44b	877.62b
	M	7.67a	16.34a	27.60b	318.86a	1057.89a

Means in the same column followed by different letters denote significant differences (LSD, $p<0.05$).

In sub-Saharan Africa, minimum tillage and mulching practices could improve soil conditions and increase crop yields (Mupangwa et al., 2013). In semi-arid conditions, tillage had no significant effect on summer maize grain yield, and the grain yield was increased with straw mulching quantity, in case of below average rainfall (Mupangwa et al., 2012). The reason of increased production of summer maize in M may be that mulching practice reduced the loss of moisture from the soil surface and increased the soil moisture which meets the need of summer maize. Due to the increase of soil moisture, more water was lost to the atmosphere through the summer maize plant transpiration instead of the surface evaporation, which means that ineffective water consumption was converted into effective water consumption (Liu et al., 2013).

Of course, this speculation is not necessarily suitable for other plants, because different crops have different growth environment and structure; for example, winter wheat grain yield was reduced in straw M in North China Plain (Li et al., 2008). In 2014, in this experiment, summer maize grain yield and yield components in M were not significantly higher than that in N; the reason may lie in the rainfall distribution, which made the production increase not very obvious in 2014. However, the mechanism remains to be further researched.

CONCLUSIONS

Straw mulching can reduce summer maize soil CO_2 emissions, increase summer maize crop carbon absorption, and increase summer maize grain yields. As a result, straw mulching is worthy of promotion as an agricultural measure for increasing carbon absorption and summer maize grain yields in North China Plain.

Acknowledgements

This work was financially supported in part by the National Science and Technology Plan Project in Rural Areas of China (2013AA102903), by the Development of Science and Technology Plan Projects in Shandong Province of China (2014GNC111002), by the Project of Shandong Province Higher Educational Science and Technology Program (J13LF06), and by Shandong Modern Agricultural Technology & Industry System (SDAIT-02-08).

REFERENCES

AL-Kaisi, M.M., Yin, X.H., 2005. *Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn-soybean rotations*. Journal of Environmental Quality, 34: 437-445.

Allen, M.R. Frame, D.J., Huntingford, C., Jones, C.D., Lowe, J.A., Meinshausen, M., Meinshausen, N., 2009. *Warming caused by cumulative carbon emissions towards the trillionth tonne*. Nature, 458: 1163-1166.

Cable, J.M., Ogle, K., Williams, D.G., Weltzin, J.F., Huxman, T.E., 2008. *Soil texture drives responses of soil respiration to precipitation pulses in the sonoran desert: implications for climate change*. Ecosystems, 11: 961-979.

Davidson E.A., Belk, E., Boone, R.D., 1998. *Soil water content and temperature as independent or confound factors controlling soil respiration in a temperature mixed hardwood forest*. Global Change Biology, 4: 217-227.

Davidson, E.A., Verchot, L.V., Cattânio, J.H., Ackerman, I.L., Carvalho, J.E.M. , 2000. *Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia*. Biogeochemistry, 48: 53-69.

Fang, C., Moncrieff, J.B., Gholz, H.L., Clark, K.L., 1998. *Soil CO_2 efflux and its spatial variation in a Florida slash pine plantation*. Plant and Soil, 205: 135-146.

Han, G.X., Zhou, G.S., Xu, Z.Z. 2008. *Temporal variation of soil respiration and its affecting factors in a maize field during maize growth season*. Chinese Journal of Ecology, 27: 1698-1705. (In Chinese)

He, J.N., Kang, W.X., Tian Z., Zhao, Z.H., Tian, D.L., Deng, X.W., 2009. *The exchange of carbon dioxide between crop system and atmosphere in GuangZhou City*. Acta Ecologica Sinica, 29: 2527-2534. (In Chinese)

Lenka, N.K., Lal, R., 2013. *Soil aggregation and greenhouse gas flux after 15 years of wheat straw and fertilizer management in a no-till system*. Soil & Tillage Research, 126: 78-89.

Kahlon, M.S., LAL, R., Ann-Varughese, M., 2013. *Twenty two years of tillage and mulching impacts on soil physical characteristics and carbon sequestration in Central Ohio*. Soil & Tillage Research, 126: 151-158.

Li, Q.Q., Chen, Y.H., Liu, M., Y., Zhou, X.B., Yu, S.L., Dong, B.D., 2008. *Effects of irrigation and straw mulching on microclimate characteristics and water use efficiency of winter wheat in North China*. Plant Production Science, 11: 161-170.

Li, R., Hou, X.Q., Jia, Z.K., Han, Q.F., Ren, X.L., Yang, B.P., 2013. *Effects on soil temperature, moisture, and maize yield of cultivation with ridge and furrow mulching in the rainfed area of the Loess Plateau, China*. Agricultural Water Management, 116:101-109.

Li, X.Y., Tang,, H.P., 2006. *Carbon sequestration: manners suitable for carbon trade in China and function of terrestrial vegetation*. Journal of Plant Ecology, 30: 200-209. (In Chinese).

Lin, E.D., 2001. *Climate Change and Agriculture Sustainable Development*. Beijing Publishing House: 1-32. (In Chinese)

Li, X.Y., Tang, H.P., 2006. *Carbon sequestration: manners suitable for carbon trade in China and function of terrestrial vegetation*. Journal of Plant Ecology, 302: 200-209. (In Chinese)

Liu, Q.R., Liu, X.H., Bian, C.Y., Ma, C.J., Lang, K., Han, H.F., Li, Q.Q., 2014. *Response of soil CO_2 emission and summer maize yield to plant density and straw mulching in the North China Plain*. The

Scientific World Journal, 2014: 8. http://dx.doi.org /10.11 5 5/20 14/180219.

Liu, Q.R., Lang, K., Zhao, D.D., Shen, J.Y., Li, Q.Q., Han, H.F., 2013. *Effects of straw mulching and plant density on water utilization of summer maize.* Journal of Drainage and Irrigation Machinery Engineering, 31: 1089-1094. (In Chinese)

Meng, L., Cai, Z.C., Ding, W.X., 2005. *Carbon contents in soils and crops as affected by long-term fertilization*. Acta Pedologica Sinica, 42: 770-776.

Mupangwa, W., Twomlow, S., Walker, S., 2012. *Reduced tillage, mulching and rotational effect on maize (Zea mays L.), cowpea (Vigna unguiculata (Walp) L.) and sorghum (Sorghum bicolor L. (Moench)) yields under semi-arid conditions*. Field Crops Research, 132: 139-148.

Mupangwa, W., Twomlow, S., Walker, S., 2013. *Cumulative effects of reduced tillage and mulching on soil properties under semi-arid conditions*. Journal of Arid Environments, 91: 45-52.

Pangle, R.E., Seiler, J., 2002. *Influence of seedling roots, environmental factors and soil characteristics on soil CO_2 efflux rates in a 2-year-old loblolly pine (Pinus taeda L.) plantation in the Virginia Piedmont.* Environmental Pollution, 116: S85-S96.

Qin, A.Z., Huang, G.B., Chai, Q., Yu, A.Z., Liu, S.B., 2011. *Impact of soil temperature and moisture on soil respiration under different cropping patterns in arid oasis area*, Our Nature, 9: 1-8.

Sangha, K.K., Jalota, R.K., Midmore, D.J., 2007. *Impact of temperature and defoliation (simulated grazing) on soil respiration of pasture grass (Cenchrus ciliaris L.) in a controlled experiment.* Agricultural, Food, and Environmental Sciences, 1: 1-9.

Schlenker, W., Roberts, M.J., 2009. *Nonlinear temperature effects indicate severe damages to US crop yields under climate change*. Proceedings of the National Academy of Sciences of the United States of America, 106: 15594-15598.

Tanveer, S.K., Wen, X., Lu, X.L., Zhang, J., Liao, Y., 2013. *Tillage, Mulch and N Fertilizer Affect Emissions of CO_2 under the Rain Fed Condition*. PLOS ONE, 8: 72140.

Wagai, R., Brye, K.R., Gower, S.T., Norman, J.M., Bundy, L.G., 1998. *Land use and environmental factors influencing soil surface CO_2 flux and microbial biomass in natural and managed ecosystems in southern Wisconsin*. Soil Biology & Biochemistry, 30: 1501-1509.

Zhang, J.W., Zheng, L., Jäck, O., Yan, D.Y., Zhang, Z.J., Gerhards, R., Ni, H.W., 2013. *Efficacy of four post-emergence herbicides applied at reduced doses on weeds in summer maize (Zea mays L.) fields in North China Plain*. Crop Protection, 52: 26-32.

Zhang, Q.B., Yang, L., Xu, Z.Z., Zhang, Y.L., Luo, H.H., Wang, J., Zhang, W.F., 2014. *Effects of cotton field management practices on soil CO2 emission and C balance in an arid region of Northwest China*. Journal of Arid Land, 6: 468-477.

Zhao, R.Q., Qin, M.Z., 2007. *Temporospatial Variation of Partial Carbon Source/Sink of Farmland Ecosystem in Coastal China*. Journal of Ecology and Rural Environment, 23: 1-6, 11. (In Chinese).