

# The spatial distribution of cropland carbon transfer in Jilin province during 2014

Xintong Cai, Jian Meng, Qiuhui Li, Shuang Gao, Xianjin Zhu \*

College of agronomy, Shenyang Agricultural University, Shenyang 110161, China

\*Corresponding author e-mail: xianjin1985@163.com

**Abstract.** Cropland carbon transfer (CCT, gC yr<sup>-1</sup>) is an important component in the carbon budget of terrestrial ecosystems. Analyzing the value of CCT and its spatial variation would provide a data basis for assessing the regional carbon balance. Based on the data from Jilin statistical yearbook 2015, we investigated the spatial variation of CCT in Jilin province during 2014. Results suggest that the CCT of Jilin province was 30.83 TgC, which exhibited a decreasing trend from the centre to the border but the west side was higher than the east. The magnitude of carbon transfer per area (MCT), which showed a similar spatial distribution with CCT, was the dominating component of CCT spatial distribution. The spatial distribution of MCT was jointly affected by that of the ratio of planting area to regional area (RPR) and carbon transfer per planting area (CTP), where RPR and CTP contributed 65.55% and 34.5% of MCT spatial distribution, respectively. Therefore, CCT in Jilin province spatially varied, which made it highly needed to consider the difference in CCT among regions when we assessing the regional carbon budget.

## 1. Introduction

Increasing the carbon sequestration of terrestrial ecosystems is regarded as an important measure to mitigate climate change [1]. However, it should base on quantifying the magnitude of regional carbon sink. There are many methods in regional carbon sink assessment, playing an important role in quantifying the regional carbon budget. The assessment method based on carbon sink shaping process, a recently proposed novel method, starts from gross primary productivity and fully considers the carbon consumption including natural and human activities. Therefore, the carbon sink shaping process based assessment not only provides an alternative data for regional carbon budget assessment, but also unravels the amount of carbon consumption during its shaping process, which sets a solid basis for increasing the carbon sequestration potential of the terrestrial ecosystems [2].

Though the carbon sink shaping process based method has certain advantages, it needs accurately assessing the values of all fluxes involving in shaping the carbon sink. However, much studies have been conducted to analyse the variation of gross primary productivity and its natural consumption such as autotrophic respiration and heterotrophic respiration, while little attention has been paid to the variation of carbon consumption caused by human activities, which inhibits the application of the carbon sink assessment method based on its shaping process.

Among all carbon fluxes caused by human consumption, cropland carbon transfer (CCT) accounts for the most portions, playing the most important role in regional carbon budget. Though there were



some studies focusing on the spatial variation of cropland carbon transfer in terrestrial ecosystems of China, they emphasized the spatial variation of cropland carbon transfer among provinces [3-5]. Therefore, they neglected the spatial difference in the same province, which inhibited the accuracy of carbon budget.

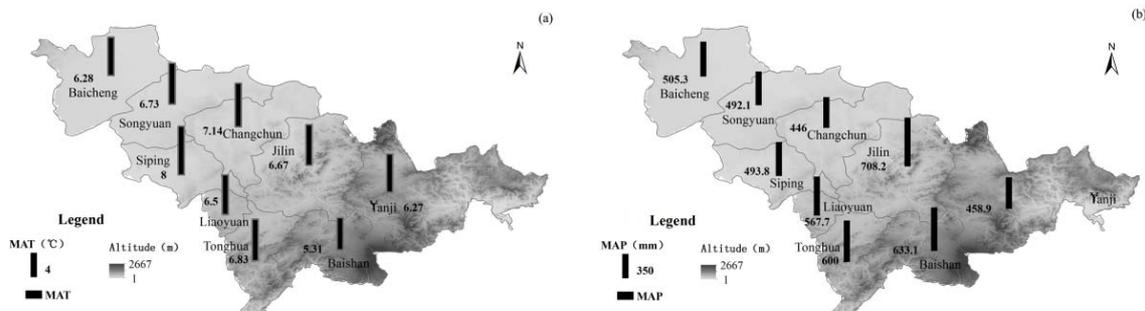
Jilin province is an important commodity grain base of China, which plays a crucial role in guaranteeing national food security [6]. Analysing the value of CCT and its spatial distribution will improve the accuracy of national carbon budget assessment, which may also provide a dataset for quantifying the regional carbon sink and its increasing potential in this area.

Therefore, based on the data from Jilin Statistical Yearbook, we analysed the spatial distributions of CCT and its components. The main objectives were to clarify: 1) what is the value of CCT in Jilin province? 2) How CCT spatially varied in Jilin province? 3) Which components dominated the spatial variation of CCT in Jilin province? Given that the difference in CCT among regions was similar among years, we selected a recent year data (2014) to conduct our study. Our results can provide a data basis for assessing the magnitude of carbon sink and its increasing potential in Jilin province, which also benefit for improving the accuracy of carbon budget assessment in China. In addition, our results also provide a reference for assessing the carbon transfer in other regions.

## 2. Material and methods

### 2.1 Brief information about the studying area

Jilin province, located in the northeast of China, includes 9 prefectural-level cities such as Changchun, Jilin, Siping, Liaoyuan, Tonghua, Baishan, Songyuan, Baicheng, and Yanji. The altitude of Jilin province ranged from 1 to 2667 m, decreasing from east towards west (Fig.1). The annual mean air temperature (MAT) of Jilin province ranged from 5.3 to 8 °C, which decreased from south to north (Fig. 1a), while annual mean precipitation (MAP) ranged from 446 to 708 mm, showing an increasing trend from west to east (Fig. 1b) [7].



**Fig.1** The spatial distributions of annual mean air temperature (a) and annual precipitation (b) of Jilin province during 2014. The background is the altitude of Jilin province.

### 2.2 CCT calculation

In this study, we calculated CCT as the product of grain yield ( $Y$ ,  $\text{g yr}^{-1}$ ), harvest index (HI), carbon content ( $C$ ), and water content ( $W$ ) as statistical yearbook only reported the value of  $Y$ . Then CCT of Jilin province was summed from each prefectural-level city and each crop.

$$\text{CCT} = \sum_{i=1}^9 \sum_{j=1}^n \{Y_{ij} \times (1 - W_{ij}) / \text{HI}_{ij}\} \times C_{ij} \quad (1)$$

Where  $Y$  is found in the Jilin statistical yearbook, and  $i$  is the number of prefectural-level city.

HI, defined as the ratio of grain yield to the sum of grain and straw yield [8], was explored to estimate the value of CCT, which can be found in Table 1. The values of HI for rice and maize were set to the average value of reported HIs in Jilin province, while these for other crops were set to the average value of China as little data were reported in this region.

The value of water content ( $W$ ) differed among crops according to previous studies [9, 10], which were listed in Table 1. Though the value of carbon content ( $C$ ) differed somewhat among crops, little effort was made to illustrate such difference. Therefore, we set  $C$  as 0.45 according to the previous study [11].

**Table 1** The values of harvest index (HI) and water content ( $W$ ) for different crops

Crops	Harvest index (HI)	Water content ( $W$ )	References
Rice	0.51	0.13	[12-14]
Maize	0.53	0.13	[15, 16]
Soybean	0.35	0.13	[17, 18]
Yam <sup>1</sup>	0.64	0.133	[19]
Other oil plants <sup>2</sup>	0.36	0.09	[19]
Sugarbeet	0.71	0.133	[19]
Tobacco	0.61	0.082	[19]
Vegetable	0.49	0.82	[4]

Note: 1 Yam HI was estimated from the average value of potato, sweet potato, and cassava in China.  
2. Other oil plants HI was estimated from the average value of peanut, rape, sesame, and sunflower in China.

### 2.3 Calculation of CCT components

CCT was the amount of organic carbon removed from cropland of the specific area in unit time, which can be deemed as the product of regional area (RA, m<sup>2</sup>) and the magnitude of carbon transfer per area (MCT, gC m<sup>-2</sup> yr<sup>-1</sup>). In addition, MCT, an important carbon flux in quantifying the regional carbon budget [20], can be regarded as the multiplication of carbon transfer per planting area (CTP, gC m<sup>-2</sup> yr<sup>-1</sup>) and the ratio of planting area to regional area (RPR, %).

Given CCT was the product of MCT and RA, MCT can be calculated as:

$$\text{MCT}=\text{CCT}/\text{RA} \quad (2)$$

Where RA can be calculated from raster calculation in ArcGIS.

Considering MCT was the product of CTP and RPR, CTP can be estimated as:

$$\text{CTP}=\text{MCT}/\text{RPR} \quad (3)$$

Where RPR can be calculated from planting area, which can be found in the statistical yearbook, and RA.

### 2.4 Causes of CCT spatial variation

In this study, we employed factor decomposition model [21, 22] to quantify the roles of CCT components in the spatial variation of CCT in Jilin province. Factor decomposition model took a logarithm operation on the specific variable and its components based on the fact that the specific variable can be deemed as the product of its components, to quantify the contributions of its components in the variation of the specific variable. Therefore, after taking the logarithm operation on CCT and its components, we can get:

$$\ln\text{CCT}=\ln\text{RA}+\ln\text{MCT} \quad (4)$$

CCT of benchmark (CCT<sub>0</sub>) and each region (CCT<sub>i</sub>) can thus be expressed as:

$$\ln\text{CCT}_0 = \ln\text{RA}_0 + \ln\text{MCT}_0 \quad (5)$$

$$\ln\text{CCT}_i = \ln\text{RA}_i + \ln\text{MCT}_i \quad (6)$$

Subtracting Eq. (5) with Eq. (6), we can get

$$\Delta\ln\text{CCT}_i = \ln\text{CCT}_i - \ln\text{CCT}_0 = \ln\text{RA}_i - \ln\text{RA}_0 + \ln\text{MCT}_i - \ln\text{MCT}_0 \quad (7)$$

Therefore, the variation of CCT changed by RA and MCT can be expressed as:

$$\Delta\text{CCT}_{\text{RA}} = \sum_{i=1}^n (\text{CCT}_i - \text{CCT}_0) \times (\ln\text{RA}_i - \ln\text{RA}_0) / (\ln\text{CCT}_i - \ln\text{CCT}_0) \quad (8)$$

$$\Delta\text{CCT}_{\text{MCT}} = \sum_{i=1}^n (\text{CCT}_i - \text{CCT}_0) \times (\ln\text{MCT}_i - \ln\text{MCT}_0) / (\ln\text{CCT}_i - \ln\text{CCT}_0) \quad (9)$$

The contributions of RA and MCT to the spatial variation of CCT were thus be expressed as  $\Delta\text{CCT}_{\text{RA}}/\Delta\text{CCT}$  and  $\Delta\text{CCT}_{\text{MCT}}/\Delta\text{CCT}$ , respectively.

To be simple, the largest value of CCT was set to the benchmark value to estimate the roles of RA and MCT in the spatial variation of CCT in Jilin province.

The contributions of MCT components, CTP and RPR, were also evaluated to clarify the cause of MCT spatial variation, which was conducted following the analysis of CCT described above.

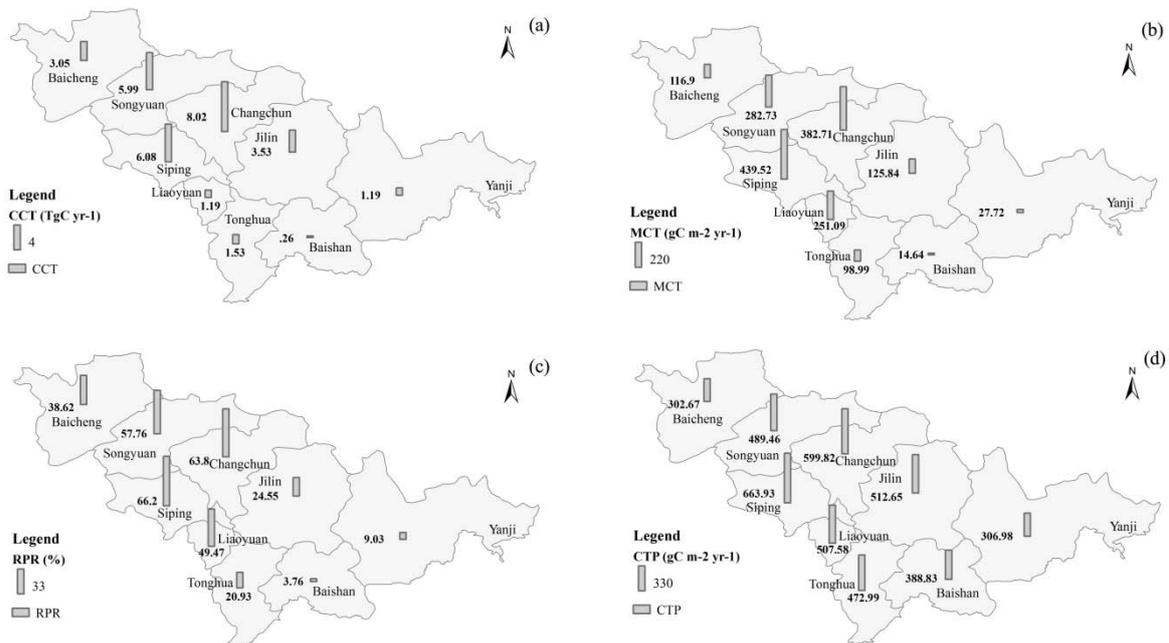
### 2.5 Statistical analysis

In this study, the data preparing were conducted by Excel 2007, while the spatial distributions of CCT, MCT, RPR, and CTP in Jilin province were drawn by ArcGIS 10.0. Other data analysis were completed in MATLAB 2014.

## 3. Results

### 3.1 The spatial distribution of CCT in Jilin province

The amount of CCT in Jilin province during 2014 was 30.83 TgC, whose spatial variation showed a decreasing trend from the centre to the border (Fig. 2a). The highest CCT appeared at the centre of Jilin province as Changchun and reached to 8.02 TgC, accounting for a quarter of CCT in Jilin province. CCT of middle-western Jilin province represented by Siping and Songyuan also had a higher CCT, which were 6.00 TgC respectively but were lower than that of Changchun. CCT of western region (represented by Baicheng) and the middle-eastern region (represented by Jilin) were comparable, which exceeded 3.0 TgC but were lower than that of middle-western region. The smallest CCT appeared at the eastern of Jilin province represented by Baishan, whose CCT was only 0.26 TgC, accounting for no more than 4% of CCT in the centre of Jilin province.



**Fig.2** The spatial distribution of cropland carbon transfer (CCT) and its components in Jilin province among Prefectural-Level cities during 2014. Panels (a)-(d) were the spatial distribution of CCT, the magnitude of carbon transfer (MCT), the ratio of planting area to regional area (RPR), and carbon transfer per planting area (CTP), respectively.

### 3.2 The spatial distribution of MCT in Jilin province

During 2014, MCT of Jilin province spatially varied ranging from  $14.64 \text{ gC m}^{-2} \text{ yr}^{-1}$  to  $439.52 \text{ gC m}^{-2} \text{ yr}^{-1}$ . The spatial distribution of MCT also showed a decreasing trend from the centre to the border but the western region had a higher MCT than the eastern region (Fig. 2b). The highest MCT appeared in the centre of Jilin province represented by Siping and Changchun, which can reach to  $400 \text{ gC m}^{-2} \text{ yr}^{-1}$ . The central region represented by Songyuan and Liaoyuan had a MCT around  $270 \text{ gC m}^{-2} \text{ yr}^{-1}$ , which was lower than that of the central region such as Siping and Changchun but was higher than that of other regions. The MCT of western region (represented by Baicheng) and middle-eastern region (represented by Jilin and Tonghua) were similar, which were all around  $100 \text{ gC m}^{-2} \text{ yr}^{-1}$ , while MCT of the eastern region such as Yanji and Baishan had the lowest MCT smaller than  $30 \text{ gC m}^{-2} \text{ yr}^{-1}$ .

### 3.3 The spatial distribution of RPR in Jilin province

As an important component of MCT, RPR substantially spatial varied ranging from 3.76% to 66.2% (Fig. 2c). The spatial distribution of RPR showed a decreasing trend from the centre to the border like MCT. The largest RPR appeared at the centre of Jilin province like Siping and Changchun, which can exceed 60%. RPR of middle-western region (like Songyuan) and middle-eastern region (like Liaoyuan) also had a high RPR around 50%. The lowest RPR appeared at the eastern of Jilin province like Baishan and Yanji, whose values were no more than 10%.

### 3.4 The spatial distribution of CTP in Jilin province

CTP, another component of MCT, also spatially varied but with a relative narrow range from  $320.67 \text{ gC m}^{-2} \text{ yr}^{-1}$  to  $664 \text{ gC m}^{-2} \text{ yr}^{-1}$ . CTP spatial distribution showed a decreasing trend from the centre to the border, while the CTP of western and southern regions were higher than those of eastern and northern regions, respectively (Fig. 2d). The highest CTP appeared at the centre of Jilin province represented by Siping and Changchun, which can exceed  $600 \text{ gC m}^{-2} \text{ yr}^{-1}$ . The middle-western and middle-eastern region such as Jilin, Liaoyuan, Tonghua, and Songyuan, also had a high CTP around  $500 \text{ gC m}^{-2} \text{ yr}^{-1}$ .

The smallest CTP appeared at the eastern and western region such as Baicheng, Baishan, and Yanji, which ranged from 300 to 400 gC m<sup>-2</sup> yr<sup>-1</sup>.

### 3.5 The relationship between CCT and its components

Results from factor decomposition suggest that the spatial variation of CCT in Jilin province was primarily caused by MCT, which accounted for 91.5% of CCT spatial variation, while the remained 8.5% spatial variation of CCT was contributed by the difference in RA among regions. Given the spatial variation of MCT, the contribution of RPR, which was 65.5%, was higher than that of CTP. CTP contributed 34.5% of MCT spatial variation.

## 4. Discussion and conclusion

In this study, we found the CCT of Jilin province during 2014 was 30.83 TgC yr<sup>-1</sup>, accounting for 1% of annual net primary productivity in China ( $2.83 \pm 0.83$  PgC yr<sup>-1</sup>) [23]. However, the CCT of Jilin province accounted for 4.89% of cropland carbon transfer in China (0.63 PgC yr<sup>-1</sup>) [4], indicating an important role of the CCT of Jilin province in the carbon budget of Chinese terrestrial ecosystems, which should be emphasized in the future.

The spatial distribution of CCT showed a decreasing trend from the centre to the border but the western region had a higher value than the eastern region, which was primarily determined by the difference in MCT. In addition, the spatial distribution of MCT was jointly affected by RPR and CTP, which may result from the topography and climate. In the western Jilin province, the altitude was low and varied little, which made this region be suitable for planting crops, while the eastern region was dominated by forests with high altitude, which made RPR in this region was small. Therefore, RPR showed a decreasing trend from west to east thus affected the spatial distribution of CCT. The southern and eastern regions had higher temperature and precipitation than the western and northern regions, while temperature and precipitation were the dominating drivers for the spatial pattern of gross primary productivity thus crop yield and CTP<sup>[24-26]</sup>. Therefore, MCT thus CCT decreased from the centre to the border but the western region was higher than the eastern region.

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## References

- [1] P. Ciais, C. Sabine, G. Bala, et al., *Carbon and Other Biogeochemical Cycles*//in T.F. Stocker, D.Qin, G. K. Platter, et al., *Climate Change 2013: The Physical Science Basis*, Cambridge and New York, Cambridge University Press, 2013: 465-570.
- [2] Q. Wang, H. Zheng, X. Zhu, et al., Primary estimation of Chinese terrestrial carbon sequestration during 2001–2010. *Science Bulletin*. 60(2015) 577-590.
- [3] Y. Huang, W. Zhang, W. J. Sun, et al., Net primary production of Chinese croplands from 1950 to 1999. *Ecological Applications*. 17(2007) 692-701.
- [4] X. Zhu, Q. Wang, H. Zheng, et al., Researches on the spatio-temporal variation of carbon consumption by agricultural and forestry utilization in Chinese terrestrial ecosystems during 2000s. *Quaternary sciences*. 34(2014) 762-768. (in Chinese with English abstract).
- [5] C. Lu, G. Xie, Y. Xiao, et al., Carbon fixation by farmland ecosystems in China and their spatial and temporal characteristics. *Chinese Journal of Eco-Agriculture*. 13(2005) 35-37. (in Chinese with English abstract).
- [6] National Bureau of Statistics of China, 2013 China Statistical Yearbook, China Statistics Press, Beijing, 2013 (in Chinese).
- [7] Bureau of Statistics of Jilin province, 2015 Jilin Statistical Yearbook, China Statistics Press,

- Beijing, 2015(in Chinese).
- [8] F. Zhang and z. Zhu, Harvest index for various crops in China. *Scientia Agricultura Sinica*. 23(1990) 83-87. (In Chinese with English abstract).
- [9] S. Piao, J. Fang, P. Ciaais, et al., The carbon balance of terrestrial ecosystems in China. *Nature*. 458(2009) 1009-1013.
- [10] Y. Bi, C. Gao, Y. Wang, et al., Estimation of straw resources in China. *Transactions of the CSAE*. 25(2009) 211-217. (in Chinese with English abstract).
- [11] J. S. Olson, J. A. Watts, L. J. Allison, Carbon in live vegetation of major world ecosystems, Oak Ridge National Lab, Tennessee, 1983.
- [12] H. Li, Y. Hou, Y. Chen, et al., Comparison of rice plant types in northeast region of China. *Acta Agronomica Sinica*. 35(2009) 921-929.(in Chinese with English abstract).
- [13] Z. Wu, G. Zhao, K. Xu, et al., Changes in photosynthetic indexes of rice varieties during forty-seven years of genetic improvement in Jilin province, China. *Chinese journal of rice science*. 23(2009) 165-171.(In Chinese with English abstract).
- [14] W. Zhang, C. Wang, L. Zhao, et al., Effects of different leaf age transplanting on yield and quality of north Japonica rice. *Anhui agricultural science bulletin*. 16(2010) 89-91.(in Chinese with English abstract).
- [15] X. Meng, H. Zhao, X. Fang, et al., Study on spring maize super high-yielding cultivation technology and analyse on factors of high yield. *Journal of Maize sciences*. 16(2008) 112-114.(in Chinese with English abstract).
- [16] Y. Xiao, C. Yang, Q. Gao, et al., Effect of ENTEC stabilized compound fertilizer on maize yield. *Journal of Maize sciences*. 17(2009) 117-119.(in China with English abstract).
- [17] M. Yuan and C. Yang, Changing low of limited branching type, dwarf and dense-resistant soybean under different densities. *Journal of Anhui agricultrual sciences*. 37(2009) 8408-8410.(in Chinese with English abstract).
- [18] H. Sun, Q. Wang, J. Li, et al., Transormation ability characteristics of dry matter in soybean. *Soybean science*. 28(2009) 233-238.(in Chinese with English abstract).
- [19] G. Xie, X. Wang, D. Han, et al., Harvest index and residue factor of non-cereal crops in China. *Journal of China Agricultural University*. 16(2011) 9-17. (In Chinese with English abstract).
- [20] D. P. Turner, A. R. Jacobson, W. D. Ritts, et al., A large proportion of North American net ecosystem production is offset by emissions from harvested products, river/stream evasion, and biomass burning. *Global Change Biology*. 19(2013) 3516-3528.
- [21] X.-J. Zhu, H.-Q. Zhang, T.-H. Zhao, et al., Divergent drivers of the spatial and temporal variations of cropland carbon transfer in Liaoning province, China. *Scientific Reports*. 7(2017) 13095.
- [22] T. Jin and J. Lu, Factor decomposition in regional disparities of grain production in Jiangsu province. *Economic Geography*. 31(2011) 1886-1896.(in Chinese with English abstract).
- [23] Y. Gao, G. Yu, L. Zhang, et al., The Changes of Net Primary Productivity in Chinese Terrestrial Ecosystem: Based on Process and Parameter Models. *Progress in Geography*. 31(2012) 109-117. (in Chinese with English Abstract).
- [24] F. S. Chapin, P. A. Matson, H. A. Mooney, *Principles of Terrestrial Ecosystem Ecology*, Springer, New York, 2012.
- [25] G.-R. Yu, X.-J. Zhu, Y.-L. Fu, et al., Spatial patterns and climate drivers of carbon fluxes in terrestrial ecosystems of China. *Global Change Biology*. 19(2013) 798-810.
- [26] X.-J. Zhu, G.-R. Yu, H.-L. He, et al., Geographical statistical assessments of carbon fluxes in terrestrial ecosystems of China: Results from upscaling network observations. *Global and Planetary Change*. 118(2014) 52-61.