Growing Season Carbon Dioxide Exchange in Flooded Non-Mulching and Non-Flooded Mulching Cotton

Zhi-guo Li¹,², Run-hua Zhang³, Xiu-jun Wang¹, Fang Chen², Chang-yan Tian¹*

1 State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, China, 2 Wuhan Botanical Garden, Chinese Academy of Sciences Key Laboratory of Aquatic Botany and Watershed Ecology, Chinese Academy of Sciences, Wuhan, China, 3 Wuhan Vegetable Research Institute, Wuhan, China

Abstract

There is much interest in the role that agricultural practices might play in sequestering carbon to help offset rising atmospheric CO₂ concentrations. However, limited information exists regarding the potential for increased carbon sequestration of different management strategies. The objective of this study was to quantify and contrast carbon dioxide exchange in traditional non-mulching with flooding irrigation (TF) and plastic film mulching with drip irrigation (PM) cotton (Gossypium hirsutum L.) fields in northwest China. Net primary productivity (NPP), soil heterotrophic respiration (Rₚ) and net ecosystem productivity (NEP) were measured during the growing seasons in 2009 and 2010. As compared with TF, PM significantly increased the aboveground and belowground biomass and the NPP (340 g C m⁻² season⁻¹) of cotton, and decreased the Rₚ (89 g C m⁻² season⁻¹) than the TF. These results demonstrate that conversion of this type of land use to mulching practices is an effective way to increase carbon sequestration in the short term in cotton systems of arid areas.

Introduction

Management and policies to increase the carbon (C) sink of agricultural soils have gained more and more attention, and it can be accepted as one of the greatest potential methods to sequester C in terrestrial ecosystems [1,2]. Different agronomic practices have been evaluated and recommended to reduce CO₂ emissions and increase C in soils such as the elimination of tillage, continuous cropping, cover cropping, using legumes in rotation and manure application [3–5]. For example, Sperow et al. [6] suggested that a change from conventional tillage to no-tillage on all currently annually cropped areas (129 Mha) in the United States could result in 47 Tg C sequestered annually. Vleeshouwers and Verhagen [7] identified animal manure incorporation and the use of straw (or crop residues) could sequester as much as 0.19 and 0.15 Mg C ha⁻¹ yr⁻¹, respectively. Although several studies have advanced the notion that changes in soil C stocks are associated with changes in crop management or in land use [1], there is still a lack of information regarding the potential C sequestration resulting from the conversion from traditional non-mulching cultivation to mulching cultivation [8].

Recently, newer cultivation technologies incorporating mulching with plastic film together with drip irrigation (PM) have been shown to increase soil temperatures and conserve soil moisture [9,10], resulting in increased crop production. PM cultivation is now widely applied in China with a bulk density of 1.56 g cm⁻³. Values of pH, electrical conductivity and total organic carbon at 0–10 cm are 8.42, 2.08 ms cm⁻¹ and 5.64 mg C g⁻¹, respectively. In 2009 and 2010, irrigation with no mulching, which was the main cropping system used in dry land agriculture in northwest China before 1980 [12]. These large land use changes alter the soil microenvironment and have significant effects on the C balance of agro-ecosystems [1]. Understanding the extent to which the conversion of TF to PM contributes to the C cycle is important for developing C management strategies in dry land areas of China.

At present, there are few studies where a complete ecosystem approach (net ecosystem productivity [NEP], net primary productivity [NPP] and soil heterotrophic respiration [Rₚ]) is used to compare the C fluxes in traditional and modern cultivations of agro-ecosystems. In this study, a full C balance approach was used to investigate short-term effects (2 years) of cotton (Gossypium hirsutum L.) conversion from TF to PM on NEP. This study aims to quantify and contrast the amount of C sequestered by the plant biomass and the C lost through soil respiration in PM and TF cotton fields, and to estimate the net gains/losses of C due to the conversion of PM to TF in dry land cotton fields.

Materials and Methods

2.1. Site Description

The study site was located at the Fukang Station of Desert Ecology (87° 56’ E, 44° 17’ N) of the Chinese Academy of Sciences at an elevation of 461 m [14]. The soil type is a clay loam with a bulk density of 1.56 g cm⁻³. Values of pH, electrical conductivity and total organic carbon at 0–10 cm are 8.42, 2.08 ms cm⁻¹ and 5.64 mg C g⁻¹, respectively. In 2009 and 2010,
daily mean air pressures ranged from 922.9 to 996.3 hPa. The daily mean air temperature had a maximum of 32°C, a minimum of −21°C, and a mean of 9.28°C. Daily mean air relative humidity showed large fluctuations, varying from 27.2 to 100%. Total annual precipitation was 164.2 mm in 2009 and 166.2 mm in 2010, slightly higher than the long-term average of 160 mm for the last 30 years.

2.2. Field Experiment
The field site has been reclaimed for 15 years from desert, and has been continuously planted cotton under plastic film mulching cultivation. In this field, we designed two treatments during the cotton growing seasons of 2009 and 2010: (1) the traditional cultivation system (TF) of flood irrigation with no mulching; and (2) a modern cultivation system using plastic film mulching with drip irrigation (PM). Each treatment was replicated three times in a randomized complete block design using plots 15 × 667 m. The cotton seeds (C.V. Xinluza No. 6) were sown on April 21, 2009, and April 28, 2010. For the PM treatment, a high density and air transparent polythene film (0.01–0.02 mm thick, 1.25 m wide) was placed over the soil surface before sowing. The seedler made small holes (0.02×0.02 m) at 0.1 m intervals within a row in the plastic film and seeds were placed into the holes, and then each hole was covered with soil. Four rows were sown on each strip of plastic film. For the TF treatment, the plants were sown as for the PM treatment. For both treatments the planting density was 266 667 plants ha−1. Irrigation models were used: drip irrigation under mulching for the PM treatment and flood irrigation for the TF treatment, and the timing of irrigation and its volume followed the local commercial practice. Nitrogen fertilizer (110 kg N ha−1) and phosphorus fertilizer (72 kg P2O5 ha−1) were applied to both treatments, and weeds were controlled by hand.

2.3. Microclimate
During the growing season of 2009 and 2010, measurements of air temperature at 30 cm and soil temperature at 10 cm in planted sites and non planted sites with and without chambers, were made for each sample by using a SN2202 digital thermo detector (Sinan Instruments Plant of Beijing Normal University, Beijing). At the same time, soil water content at 10 cm in each plot was measured with the oven drying method (105°C for 48 h).

2.4. Growth Analysis
From May 10 to October 20 in 2009 and 2010, five 50×50 cm quadrats were randomly selected from both the PM and the TF every 25 days after planting. The above ground biomass in each quadrat was clipped to ground level and put in large brown paper bags. The below ground biomass was determined by the excavation of 50×50 cm pits at the same time to a depth of 70 cm in 20 cm increments. The live below ground biomass in each quadrat was collected and put in large brown paper bags. Biomass samples were washed in a series of five de-ionized water baths and weighed after oven drying for 5 days at 75°C. Grain yield, for each plot, was determined on three 4-m2 subsplots. Organic C was measured by oxidation with K2CrO7 according to the method of Liu et al. [15].

2.5. Net Primary Productivity
In this study, the cotton NPP was calculated by the measurement of above and below ground biomass during the different cotton periods and the C content using the following equation:

\[ NPP_i = (Bb_i - Bb_{i-1}) \times Cb + (Ba_i - Ba_{i-1}) \times Ca \]  

where \( i \) is the measurement time of the plant biomass, \( Bb \) is the below ground biomass (g m⁻²), \( CB \) (g C g⁻¹) is the carbon content of the below ground biomass, \( Ba \) is the above ground biomass (g m⁻²), \( Ca \) (g C g⁻¹) is the carbon content of the above ground biomass.

2.6. Soil Heterotrophic Respiration (Rsh) Measurements
Soil heterotrophic respiration was measured at midday using a closed opaque chamber (0.5×0.5×0.5 m), which has been a method used in previous studies [16,17]. The chamber was equipped with a small circulation fan and a gas channel, which was a PVC tube with a three-way stopcock. A stainless steel frame with a water groove (0.5×0.5×0.05 m) was inserted into the soils, and the chamber was put into a groove that was filled with water before each gas sampling to ensure an airtight seal.

Three steel frames were placed between cotton rows in each replicate. Nylon nets (200 cm long×50 cm height, mesh size 0.25 mm) were buried around the frame to prevent roots entering the soil below the frames. When conducting gas sampling, the gas was collected mostly between 9 and 11 am every other week. The fluxes measured during this time in the morning are regarded to be basically representative for the daily average fluxes [18,19]. About 70 mL of gas was aspirated from the chamber at 30-s intervals for 150 s after capping. Gas samples were collected in polyethylene coated aluminum gas bags and taken into the laboratory soon after sampling. CO2 concentrations were analyzed using a modified gas chromatograph (Agilent 4890D) equipped with an electron capture detector and a hydrogen flame ionization detector. The flux of soil heterotrophic respiration was calculated as follows:

\[ F = \rho \times V/A \times \Delta C/\Delta t \times 273/T \times \alpha \] 

where \( F \) (g C m⁻² h⁻¹) refers to flux of soil heterotrophic respiration, \( \rho \) is the density of CO2 (1.98×10⁻⁶ g m⁻³) under standard conditions, \( F \) (m³) and \( A \) (m²) are the volume and bottom area of the chamber, \( \Delta C \) (m³ m⁻³) is the change in CO2 concentration in the chamber during the period \( \Delta t \) (h), \( T \) is the absolute temperature and \( \alpha \) is the conversion factor for CO2 to C (12/44).

2.7. Growing Season Net Ecosystem Productivity (NEP) Measurements
NEP is a comprehensive measure of net carbon accumulation by ecosystems. Growing season NEP can be calculated as the difference between the season NPP and season \( Rsh \):

\[ \text{seasonNEP} = \text{seasonNPP} - \text{seasonRsh} \]

\[ = \sum_{i} \text{NPP}_i - \sum_{j} \frac{X_j + X_{j+1}}{2} (t_{j+1} - t_j) \] 

where season \( Rsh \) represent cumulative soil CO2 emissions throughout the cotton growing season; \( i \) and \( j \) are the measurement times of the plant biomass and soil respiration; \( X_j \) (g C m⁻² d⁻¹) is the first week CO2 measurement and \( X_{j+1} \) (g C m⁻² d⁻¹) is the following week CO2 measurement at times \( t_j \) and \( t_{j+1} \), respectively; and \( n \) is the final week of CO2 measurement during the experiment periods.

2.8 Statistical Analysis
Data comparisons between PM and TF sites were performed by one-way ANOVA using SPSS 11.0 software. Averages from all...
treatments were compared using Fisher’s least significant difference at a probability level of 0.05.

Results

3.1. Soil Temperature and Soil Water Content

The mean daily soil temperature showed a marked seasonal trend during the growing season for all years and all sites, and both PM and TF had higher mean annual values in 2010 than in 2009 (Fig. 1). Soil temperature in the PM was significantly higher than in TF during the early growing season (April to July) \( p < 0.05 \); however, at the mid-late growth stage (after August), the daily average temperature in PM was obviously lower than that in TF, particularly in 2010. Soil water contents for PM and TF were also higher in 2010 than in 2009 during the growing period. The PM had a significant higher soil water content during the growing period than the TC treatment \( p < 0.05 \), but the difference was larger in 2009 than 2010.

3.2. NPP

Daily NPP values relative to the whole growing period (April to November) were computed for both land uses. The time series graphs of NPP from PM and TF (Fig. 2) showed large fluctuations ranging from 0.17 to 15.12 g C m\(^{-2}\) d\(^{-1}\) during the whole growing period. NPP increased to the highest levels in July and August but remained at a low level during the early (May–July) and late (October) growing season. Overall, the average daily rates of NPP in the PM were significantly higher than in the TF, especially during the main growth periods where PM (15.12 g C m\(^{-2}\) d\(^{-1}\)) was approximately 1.5 times higher than TF (9.4 g C m\(^{-2}\) d\(^{-1}\)) \( p < 0.05 \). Total NPP for the PM during the whole growing season was 1030 g C m\(^{-2}\) season\(^{-1}\) which was significantly higher than the 689 g C m\(^{-2}\) season\(^{-1}\) for the TF (Table 1) \( p < 0.001 \). In the 2nd year of measurement (2010), total NPP on both the PM and PF sites was less than the 1st year (2009) probably because an insect pest infestation broke out during the main cotton growing period (July). However, PM did show a higher total NPP than TF, although the difference was smaller.

Figure 1. Soil temperature and soil water content measured at 10 cm depth in the traditional cultivation system of flood irrigation with no mulching (TF) and the modern cultivation system using plastic film mulching with drip irrigation (PM) in the cotton growing season of 2009 and 2010.
doi:10.1371/journal.pone.0050760.g001
3.3. Soil Respiration
Soil respiration also showed strong seasonal variations with occasionally high fluxes of 2.12–4.12 g C m⁻² d⁻¹ between July and August (Fig. 2). The average daily rate of \( R_h \) was 1.86 g C m⁻² d⁻¹ in the PM, significantly higher than the values of 1.39 g C m⁻² d⁻¹ in the TF (\( p < 0.05 \)). During the two growing seasons, the total soil CO₂ flux in the PM was lower than that in the TF (485 and 663 g C m⁻², respectively). Thus, the conversion from TF to PM caused a decrease in soil C emissions of approximately 89 g C m⁻² in one growing season.

3.4. Growing Season NEP
Between years, the values of \( \Delta P \) from PM and TF varied largely owing to the large fluctuation of \( NPP \) for both sites. Comparing \( \Delta P \) from the two sites, PM was 479 and 379 g C m⁻² season⁻¹ higher than TF in 2009 and 2010 growing season, respectively. Over the two growing periods, PM had a net C uptake of 1234 g C m⁻² and TF had a net C uptake of 376 g C m⁻² from the atmosphere (Table 2).

Table 1. Crop management details for the two cultivation systems in the cotton growing season of 2009 and 2010 (± standard deviation where computed, \( n = 3 \)).

| Treatment  | Year       | Tillage date | Planting date | Applied N (kg N ha⁻¹) | Harvest date | Cotton yield (Mg ha⁻¹) |
|------------|------------|--------------|---------------|-----------------------|--------------|-----------------------|
| PM         | 2009       | Dec. 20, 2008| Apr. 21, 2009 | 110                   | Oct. 18      | 4.41±0.37             |
|            | 2010       | Dec. 15, 2009| Apr. 29, 2009 | 110                   | Oct. 20      | 3.89±0.58             |
| TF         | 2009       | Dec. 20, 2008| Apr. 21, 2009 | 110                   | Oct. 18      | 3.34±0.64             |
|            | 2010       | Dec. 15, 2009| Apr. 29, 2009 | 110                   | Oct. 20      | 2.85±0.23             |

*PM = plastic film mulching with drip irrigation; TF = non-mulching with flooding irrigation.

doi:10.1371/journal.pone.0050760.t001
Table 2. Carbon balance components for the PM and TF fields in the cotton growing season of 2009 and 2010 (±SD, n = 3).

| Date     | Site | NPPa g C m⁻² | Rb g C m⁻² | NEPc g C m⁻² |
|----------|------|--------------|------------|--------------|
| 2009.4–2009.11 | PM   | 1030±155 a   | 786±49 a   | 244±33 b     |
|          | TF   | 648±96 b     | 311±29 a   | 337±21 b     |
| 2010.4–2010.11 | PM   | 689±97 a     | 271±19 b   | 418±15 a     |
|          | TF   | 391±73 b     | 352±32 a   | 39±19 b      |
| Total    | PM   | 1719±121 a   | 485±31 b   | 1234±72 a    |
|          | TF   | 1039±78 b    | 663±49 a   | 376±49 b     |

a NPP = net primary productivity;  
b Rb = heterotrophic respiration;  
c NEP = net ecosystem productivity; In a row, values with the different letters are significant different at 5% level based on Fisher’s least significant difference tests.

doi:10.1371/journal.pone.0050760.t002

Discussion

In cropland, improved practice can reduce net CO₂ emissions from soils and stabilize and/or increase C sequestration in the soil, and is being accepted as the best potential method to assist in meeting the demands of an international C credit system [1–4]. In this study, the consequences of modern and traditional cultivation management options for C fluxes were investigated using a plastic film mulching management with drip irrigation, versus a non-mulching management with flood-irrigation. It was assumed that all differences between the mulching and non-mulching cropland plots resulted from the contrast in management.

The NPP [g C dry matter produced per unit leaf area and time], referred to as the net CO₂ uptake by canopy, is a primary determinant of the C flux into the terrestrial biomass [20]. PM significantly increased cotton NPP compared with TF, although the difference between PM and TF was smaller in the 2nd year owing to an insect pest infestation. This PM effect was also found in the earlier results for cotton in the Yellow River Delta China [21], and other crops such as wheat in New Delhi, India [22], and tomato in Mancha, Spain [23]. On the PM site, suitable soil conditions could be established with rational fertilizer use [24], high soil temperature and soil moisture [10], and better weed control [25], which could increase the photosynthetic capacity of crop leaves and lead to an increase in plant C content. Li et al. [11] and Chakraborty et al. [22] attributed the higher NPP in the PM to the improvement of water use efficiency compared with TF. The increase of water use efficiency in PM is reflected in two aspects: prolonging the soil water retention time in soil by reducing soil water evaporation, and exploiting deep soil water. These changes reduced the water stress, triggered deep root growth and improved plant photosynthesis, which resulted in the obvious increase in NPP at the PM sites. Liu et al. [26] and Li et al. [11] also reported that the higher soil temperature of PM, particularly at early seedling growth, reduced cell damage from early season chilling and produced larger and more vigorous seedlings compared with TF, and these seedlings then sequestered more CO₂ from the atmosphere during the growth period.

Besides the obvious increase in NPP (C input), PM also changed soil CO₂ fluxes (C output). Conversion from PM to TF greatly altered soil environment factors such as temperature, plant and microorganism activity, and soil organic carbon content. These factors regulate soil CO₂ production through biochemical action, autotrophic and heterotrophic respiration [27,28], and other soil properties such as soil water content and soil porosity, which affects the transfer of CO₂ in the soil profile [29]. In this study, the soil surface CO₂ flux was significantly lower in PM than in TF during the whole growth period. The result was opposite to what was expected, because previous studies reported that higher soil temperature and soil water content due to mulching increased soil respiration. The lower CO₂ in PM may be related to the soil properties. The soils in the present study sites were rich in calcium ions and had a high pH of 8.42 [30], together with a higher soil water content, which possibly led to a favorable soil environment for the formation of carbonate or organo-mineral complexes [31]. Moreover, mulching decreases wind disturbance, which can induce pressure pumping and vertical advection and increase rates of CO₂ exchange between soil and the atmosphere over and above rates permitted by molecular diffusion alone [32].

NEP, an index of ecosystem function related to CO₂ uptake depends on two contrasting processes: NPP and Rb. Due to lower Rb than NPP in arid cropland, the mean NEP values of 188–617 g C m⁻² season⁻¹ in these cotton systems were both positive and much greater than those observed at forest sites (Borden forest, Ontario: 65–140 g C m⁻² season⁻¹ [33]; European forest: 173 g C m⁻² season⁻¹ [34]; Harvard forest, MA: 174 g C m⁻² [35]), and grassland sites (northern temperate grassland in Alberta, Canada: –18 to 20 g C m⁻² [36]; Mediterranean annual grassland in California: –30 to 190 g C m⁻² [37]). As, we reported the NEP values with regard to single cotton growing season in this study, not surprisingly, the NEP values were higher than those reported on yearly basis in other studies. The growing season NEP values on the irrigated and rainfed maize sites at the University of Nebraska Agricultural Research and Development Center range from 600–900 g C m⁻², which approach those of cotton in our study [38]. In addition, in this region, there is plenty of sunshine during growing season, and hence we used the high density cultivation mode. This mode could produce a higher level of NPP. These reasons eventually led to higher NEP than in other studies.

However, as a consequence of an increase in NPP and a relative reduction in Rb rates, PM showed a higher NEP (C sequestration potential) and sequestered an average of 429 g C m⁻² season⁻¹ more than TF. Similarly, Saroa et al. [39], Jia et al. [40] and Liu et al. [41] reported that net C content in soil significantly increased in soils following the initial conversion to PM. However, these results are in contrast with Zhang et al. [42], who measured significant net losses of SOC in PM soil due to accelerated decomposition of organic matter under the prevailing conditions of higher soil temperature and moisture. The different C content results after conversion to PM were probably due to differences in soil properties and crop species. In the present study, crop soils are rich in calcium ions, have a high pH (8.42) and have a lower SOC content [30], which provided conditions for the formation of carbonate or organo-mineral complexes [31]. Also, cotton has a larger biomass and deeper root systems that was more suitable for sequestering larger amounts of C into the soil profile [43,44].

Despite these analyses, mulching cultivation still has a relatively finite C sequestration potential. According to results reported by Li et al. [45] and Chen et al. [46], mulching increased the amount of CO₂ released from soil because the higher soil temperature accelerated the decomposition of soil organic matter. To improve the performance of C sequestration by the PM ecosystem, we suggest that the mulching cultivation system should be integrated with other highly advanced technological methods such as using no-till practices [47], planting biofuel crops with a greater biomass [48], adopting practices that encourage deep rooting of crops that allocate more C and nutrients deep into the soil profile [49] or...
adding black biochar into the soil to fix more CO2 from soil respiration.

Conclusion
This study shows that conversion from mulching cultivation to non-mulching cultivation in the short term increased the share of cotton NPP (C input) and decreased the soil surface CO2 flux (C output) by ~20% for the whole growing season. As a consequence, there was a net increase of C in terms of NPP of ~429 g C m^-2 season^-1 after converting to PM cultivation. Nevertheless, to make the mulching cultivation sequester more C from the atmosphere into the soil, it was suggested that other C fixing practices are used in conjunction with the mulching cultivation. Furthermore, in order to assess the overall greenhouse gases balance after the conversion from PM to TF, experimental measurements on N2O and CH4 fluxes are needed.

Author Contributions
Conceived and designed the experiments: ZGL XJW FC CYT. Performed the experiments: ZGL RHZ. Analyzed the data: ZGL XJW FC. Contributed reagents/materials/analysis tools: ZGL RHZ CYT. Wrote the paper: ZGL.

References
1. Johnson JMF, Franzluebbers AJ, Weyers SL, Reicosky DC (2007) Agricultural opportunities to mitigate greenhouse gas emissions. Environmental Pollution 150: 167–124.
2. Dejsardins RL, Smith W, Grant B, Campbell C, Runak R (2005) Management strategies to sequester carbon in agricultural soils and to mitigate greenhouse gas emissions. Climatic Change 70: 283–297.
3. Yam HM, Cao MK, Liu JY, Yao B (2007) Potential and sustainability for carbon sequestration with soil and tillage improved soil management in agricultural soils. Chinese Agriculture Ecosystems & Environment 121: 325–335.
4. Paustian K, Six J, Elliott ET, Hunt HW (2000) Management options for reducing CO2 emissions from agricultural soils. Biogeosciences 6: 147–163.
5. Li CF, Zhou DN, Kou ZK, Zhang ZS, Wang JP, et al. (2012) Effects of tillage and nitrogen fertilizers on CH4 and CO2 emissions and soil organic carbon in paddy fields of central China. Plos One 7: 1–9.
6. Sperow M, Eve M, Paustian K (2005) Potential soil C sequestration on US cropland. Climatic Change 71: 919–936.
7. Vleeshouwers LM, Verhagen A (2002) Carbon emission and sequestration by agricultural land use: a model study for Europe. Global Change Biology 8: 519–530.
8. Okuda H, Noda K, Sawamoto T, Tsuruta H, Hirabayashi T, et al. (2007) Alkaline ash carbon sequestration in rice fields. Soil & Tillage Research 98: 263–272.
9. Zhang SL, Lovshahl I, Grip H, Tong VN, Yang XY, et al. (2009) Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China. Soil & Tillage Research 102: 78–86.
10. Li FM, Wang J, Xu JZ, Xu HL (2004) Productivity and soil response to plastic film mulching durations for spring wheat on semiarid Loess Plateau of China. Soil & Tillage Research 78: 9–20.
11. Zhang CQ, Zhang SF, Yang JC, Zhang JH (2000) Yield, grain quality and water use efficiency of rice under non-flooded mulching cultivation. Field Crops Research 108: 71–81.
12. He WP, Yan CR, Zhao CX, Zhang RR, Liu Q, et al. (2009) Study on the use efficiency of rice under non-flooded mulching cultivation. Field Crops Research 112: 299–231.
13. Teklemariam T, Staehler RM, Barr AG (2009) Eight years of carbon dioxide exchange above a mixed forest at Bordan, Ontario. Agricultural and Forest Meteorology 149: 2040–2053.
14. Ahmed ZI, Ansar M, Iqbal M, Minhas NM (2007) Effect of planting geometry of potato (Solanum tuberosum L.) under coloured plastic mulch. Society for Horticultural Science 76: 279–287.
15. Bellassen V, Viovy N, Luyssaert S, Le Maire G, Schelhaas MJ, et al. (2011) Reconstruction and attribution of the carbon sink of European forests between 1950 and 2000. Global Change Biology 17: 3274–3292.
16. Hollinger DY, Aber J, Dail B (2004) Spatial and temporal variability in forest-atmosphere CO2 exchange (vol 10, pg 1689, 2004). Global Change Biology 10: 1951–1957.
17. Flanagan LB, Wever LA, Carlson PJ (2002) Seasonal and interannual variation in carbon dioxide exchange in a northern temperate grassland. Global Change Biology 8: 599–615.
18. Xu LF, Baldocchi DD (2004) Seasonal variation in carbon dioxide exchange over a Mediterranean annual grassland in California. Agricultural and Forest Meteorology 123: 79–96.
19. Verma SB, Dobermann A, Cassman KG, Walters DT, Knoops JM, et al. (2005) Annual carbon dioxide exchange in irrigated and rainfed maize-based agroecosystems. Agricultural and Forest Meteorology 131: 77–96.
20. Saroja GS, Lal R (2003) Soil restorative effects of mulching on aggregation and carbon sequestration in a mimian soil in central Ohio. Land Degradation & Development 14: 481–493.
21. Jia Y, Li FM, Wang XL (2006) Soil quality responses to alfalfa watered with a field micro-catchment technique in the Loess Plateau of China. Field Crops Research 95: 64–74.
22. Chakraborty D, Nagarajan S, Aggarwal P, Gupta VK, Tomar RK, et al. (2008) Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum aestivum L.) in a semi-arid environment. Agricultural Water Management 95: 1323–1344.
23. Moreno MM, Moreno A (2008) Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop. Scientia Horticulturae 116: 256–263.
24. Gao YJ, Li Y, Zhang JC, Liu WG, Dang ZP, et al. (2009) Effects of mulch, N fertilizer, and plant density on wheat yield, wheat nitrogen uptake, and residual soil nitrate in a dryland area of China. Nutrient Cycling in Agroecosystems 85: 109–121.
25. Ahmed ZI, Ansar M, Iqbal M, Minhas NM (2007) Effect of planting geometry and mulching on moisture conservation, weed control and wheat growth under rainfed conditions. Pakistan Journal of Botany 39: 1189–1195.
26. Liu XJ, Wang JC, Lu SH, Zhang FS, Zeng XZ, et al. (2003) Effects of non-flooded mulching cultivation on crop yield, nutrient uptake and nutrient balance in rice-wheat cropping systems. Field Crops Research 83: 297–311.
27. Billings SA, Ziegler SE (2008) Altered patterns of soil carbon substrate usage and heterotrophic respiration in a pine forest with elevated CO2 and N fertilization. Global Change Biology 14: 1023–1036.
28. Saito M, Kato T, Tang Y (2009) Temperature controls ecosystem CO2 exchange of an alpine meadow on the northeastern Tibetan Plateau. Global Change Biology 15: 221–228.
29. Reth S, Gockele M, Falge E (2005) CO2 efflux from agricultural soils in Eastern Germany — comparison of a closed chamber system with eddy covariance measurements. Theoretical and Applied Climatology 80: 105–120.
30. Xie JX, Li Y, Zhao CX (2009) CO2 absorption by alkaline soils and its implication to the global carbon cycle. Environmental Geology 56: 953–961.
31. Mi N, Wang SQ, Liu JY, Yu GR, Zhang WJ, et al. (2008) Soil inorganic carbon storage pattern in China. Global Change Biology 14: 2380–2387.
32. Reicosky DC, Gesch RW, Wagner SW, Gilbert RA, Wente CD, et al. (2008) Tillage and wind effects on soil CO2 concentrations in muck soils. Soil & Tillage Research 99: 221–231.
33. Moreno MM, Moreno A (2008) Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop. Scientia Horticulturae 116: 256–263.
34. Hollinger DY, Aber J, Dail B (2004) Spatial and temporal variability in forest-atmosphere CO2 exchange (vol 10, pg 1689, 2004). Global Change Biology 10: 1951–1957.
35. Flanagan LB, Wever LA, Carlson PJ (2002) Seasonal and interannual variation in carbon dioxide exchange in a northern temperate grassland. Global Change Biology 8: 599–615.
36. Xu LF, Baldocchi DD (2004) Seasonal variation in carbon dioxide exchange over a Mediterranean annual grassland in California. Agricultural and Forest Meteorology 123: 79–96.
37. Verma SB, Dobermann A, Cassman KG, Walters DT, Knoops JM, et al. (2005) Annual carbon dioxide exchange in irrigated and rainfed maize-based agroecosystems. Agricultural and Forest Meteorology 131: 77–96.
38. Saroja GS, Lal R (2003) Soil restorative effects of mulching on aggregation and carbon sequestration in a mimian soil in central Ohio. Land Degradation & Development 14: 481–493.
39. Jia Y, Li FM, Wang XL (2006) Soil quality responses to alfalfa watered with a field micro-catchment technique in the Loess Plateau of China. Field Crops Research 95: 64–74.
40. Liu CA, Jin SL, Zhou LM, Jia Y, Li FM, et al. (2009) Effects of plastic film mulch and tillage on maize productivity and soil parameters. European Journal of Agronomy 31: 241–249.
41. Zhang GS, Chan KY, Li GD, Huang GB (2008) Effect of straw and plastic film mulch management under contrasting tillage practices on the physical properties of an erodible loess soil. Soil & Tillage Research 100: 115–119.
42. McMichael BL, Oosterhuis DM, Zak JC, Beyrouthy CA (2010) Growth and development of root systems. Physiology of Cotton: 57–71.
44. Tam M, Gunther KP (2011) Validating modelled NPP using statistical yield data. Biomass & Bioenergy 35: 4665–4674.
45. Li SQ, Li FM, Song QH, Wang J (2001) Effects of plastic film mulching periods on the soil nitrogen availability in semi-arid areas. Acta Ecologica Sinica 21: 1519–1526.
46. Chen XS, Guo S, Wang JK, Zhang J (1998) Effect of mulching cultivation with plastic film on soil microbial population and biological activity. Chinese Journal of Applied Ecology 9: 435.
47. Sombrero A, de Benito A (2010) Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. Soil & Tillage Research 107: 64–70.
48. Heaton E, Vong T, Long SP (2004) A quantitative review comparing the yields of two candidate C4 perennial biomass crops in relation to nitrogen, temperature and water. Biomass & Bioenergy 27: 21–30.
49. Bernacchi CJ, Hollinger DE, Meyers T (2005) The conversion of the corn/soybean ecosystem to no-till agriculture may result in a carbon sink. Global Change Biology 11: 1067–1072.