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Original Research

Conversion of Cropland to Grassland and Forest Mitigates Global Warming Potential in Northeast China

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Abstract

In converting cropland to grassland and forest, more carbon is sequestered in grassland soil and forest biomass, but the mitigation of global warming potential (GWP) is not clear. In this study, we use the long-term conversion from cropland to grassland (28 y) and forest (14 y) to comprehensively assess the impact on GWP of soil carbon (C), nitrogen (N), CO_2, and N_2O emissions. The results showed that compared to the original cropland, conversion to grassland increased soil C content by 51.1%, soil N content by 28.4%, soil C stock (SCS) by four times, CO_2 emission by 17%, and N_2O emission by 40%; soil N stock (SNS) decreased by half. The corresponding values after afforestation were 7.2%, 5.2%, three times, 3%, -80%, and half, respectively. Overall GWP in the cropland system was calculated using the fuel used for farming production, the change in soil C, and N_2O emissions. Due to large C sequestration, the GWP of conversion to grassland (-1667 kg CO_2-C equivalent $ha^{-1}\cdot y^{-1}$) and forest (-324 kg CO_2-C equivalent $ha^{-1}\cdot y^{-1}$) were significantly lower than the cropland system (755 kg CO_2-C equivalent $ha^{-1}\cdot y^{-1}$). The relationship between GWP and greenhouse gas, between GWP and the change of total C and N, suggest that in rain-fed agricultural systems in northeast China, the conversion from cropland to grassland and forest can mitigate GWP through changing CO_2 and N_2O emissions.

Keywords: land use change, CO_2 and N_2O emissions, change in soil carbon stock (SCS), global warming potential (GWP)

Introduction

Global warming is now recognized as a major threat to natural and socio-economic systems with rapid population growth and economic development around the world [1, 2]. Increasing anthropogenic contributions to atmospheric greenhouse gas concentrations [3] and changes in soil carbon and nitrogen stocks [4] are critical sources for global warming. Afforestation and establishment of grasslands on previously cropped sites are considered to be effective and cost-efficient mitigative response strategies to climate change because of the ability of forest and grassland sites to sequester CO_2 from the atmosphere and store more C and N [5, 6].

It is well documented that land use change affects soil carbon stocks (SCS) [7-11] and greenhouse gas (GHG) emissions [2, 12-14]. However, with the population growing and diets changing in developing countries, more land is required for agriculture to meet food demands [15, 16]. Changing grassland to cropland systems in temperate regions has resulted in losses of soil organic C (SOC) from 18% to 29%. By 2010, land use change was responsible for

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about 30% of the increase in atmospheric CO_2 [2], 7% of the increase in N_2O [13], and less than 1% of the increase in CH_4 emissions [17, 18]. Converting farmland to grassland or forest becomes a valid and potentially useful means for SOC restoration and GHG mitigation.

When farmland is abandoned, SOC stocks can significantly increase after conversion to pasture (19%) and tree plantations (18%) [10]. These increases depend on the amount of rainfall [8], clay content of soil, and vegetation species [19]. Following such transitions, there is an increase in organic matter inputs to the soil and reduced atmospheric CO_2 concentration because of the ability to sequester C in vegetation and soil [20]. In the soil, microclimatic conditions such as microbial community, moisture, and temperature will be modified by the transition. Small changes in the SOC pool could have dramatic impacts on atmospheric CO_2. The response of SOC to global warming is of critical importance [15].

Accounting for GHG emissions and global warming potential (GWP) of cropping systems requires evaluating their net impact on all emissions associated directly and indirectly with crop production [21]. GHG emissions are associated with agricultural inputs (machinery, seed, fertilizer, and agrochemical production) and diesel fuel used in farm operations [21]. Insect damage also removes C from the ecosystem. With global warming recognized as a major threat to natural and socio-economic systems, China recently launched the 'Grain-for-Green' Program, stimulating the conversion of cropland to forest and grassland [10]. The average increase in SOC stocks was 26% after cropland conversion to forest [8]. Restoration of cropland back to grassland systems may restore 7-18% of native C stocks over a 20-year period in temperate moist and dry climates [22, 23]. However, Laganiere et al. [19] in a review of 33 recent publications, showed that afforestation has had mixed results, leading to decreases, increases, and negligible effects on SOC stocks. Of these references, only Wang et al. [24] identified former arable soils as a sink for CO_2 after conversion to forest in the temperate continental monsoon climate of northeast China. In China, the largest grain producing area is located in the northeast. It is therefore imperative to understand the extent of the effect of conversion of cropland to forest and grassland on GHG emissions and GWP in northeast China.

Not only is the decrease in cropland area a major driver of changes in GHG emissions, it is often the limiting factor for crop production and therefore a dominant driver of area-scaled GWP. Although food demand can often be obtained with fertilizer management, the question is whether the decrease in cropland area is large enough to offset the corresponding decrease in GHG emissions, resulting in an overall lower area-scaled GWP. Furthermore, much research has focused on changes in SCS, with little on SNS. Therefore, we hypothesized that:

(i) the primary contributing factors to GWP are different among cropland, grassland, and forest
(ii) the lowest GWP is achieved with the largest changes in SCS and SNS

Materials and Methods

Site Description, Climate and Management

The study was conducted on a typical Mollisol belt in Hailun County, Heilongjiang Province, China (N47º26′, E126º38′). The mean annual temperature is 1.5ºC and annual precipitation is 550 mm with 65% from June to August. The duration of the frost-free period is about 120 days. The local climate is a semi-humid temperate continental monsoon climate with long, cold winters (November to March). The winter is dry with snow cover beginning in November and snow-melt occurring in early April. The soil is classified as *Pachic Haploborolls* in the US system. The soil is a silty clay loam with 40% clay [25].

The studied soil was sampled from three land-use systems named as three treatments. The study location did not need specific permissions for these studies. We confirmed that the field studies did not involve endangered or protected species. The GPS coordinates of grassland, forest, and cropland were (N47º26′23", E126º38′12"), (N47º26′24", E126º38′59"), and (N47º26′14", E126º38′12"). Before conversion, the three land-use systems had the same cropping history. They included:

i) grassland, which was converted to grassland from cropland in 1985 (total C, 33.3 $g\cdot kg^{-1}$; total N, 2.3 $g\cdot kg^{-1}$). Total area is 1.0 hm^2 of meadow steppe vegetation restoration, and the dominant species of foxtail (*Leymus chinesis*);
ii) forest, conversion of cropland to forest in 2000 (total C, 27.3 $g\cdot kg^{-1}$; total N, 1.9 $g\cdot kg^{-1}$) leading to 5.6 hm^2 total pine area;
iii) cropland, an experiment set up in 1985 (total C, 33.3 $g\cdot kg^{-1}$; total N, 2.3 $g\cdot kg^{-1}$) with a maize-soybean-wheat rotation.

The area is 60 m^2, four replicates. The fertilizer application was N ($kg\cdot ha^{-1}$) 20.25 for soybean, 112.5 for maize and wheat (62.5 $kg\cdot N\cdot ha^{-1}$ as basal fertilizer at planting, and 50 $kg\cdot N\cdot ha^{-1}$ as supplemental fertilizer in July during maize growing season); P_2O_5 ($kg\cdot ha^{-1}$) 54.75 for soybean, 45 for maize and wheat; K_2O ($kg\cdot ha^{-1}$) 30 for three crops, applied separately.

Soil and Gas Sampling and Analysis

The soils were sampled in October 2013 with the following procedure. Each land-use system was seen as one treatment with four replicates. In cropland, a sampling site distributed six representative points in each replicate. In grassland and forest, the sampling site located the focus of the same horizontal line as cropland and the vertical central of grassland or forest. Six destructive soil samples for each treatment were taken using a soil auger to make a composite sample from the soil profile (0-100 cm). Before mixing the soil sample, subsamples were used to measure soil density. One composite soil sample was made up from each 20-cm soil profile. The composite sample was homogenized after being air-dried. The soil carbon and nitrogen content were analyzed an using ELEMENT III CHNSO analyzer (Germany).

A static chamber technique was used for gas collection from Jan./2006 to Dec./2008. Chambers were cylindrical with a volume of 0.042 m^3, surface area of 0.14 m^2, and height of 0.3 m. Each chamber was equipped with a fan to mix air and a thermocouple to record temperature in the headspace. Gas was collected at regular intervals (0, 10, 20, and 30 min) from closed chambers using a syringe from 10:00 to 11:00 and was injected into 18 ml evacuated vials. Sampling was done twice each week. Samples were analyzed using a gas chromatograph with an ECD for N_2O (Shimadzu, GC2010, Japan) and with an FID for CO_2 after CH_4 conversion furnace (Shimadzu GC2010, Japan). Standard gases of CO_2 and N_2O were supplied by Haipu Corp. (Beijing, China). The rate of change in chamber concentration was calculated with linear regression.

Calculation

Gas flux

$$SF_{CO_2} = \rho_1 \frac{dc}{dt} \times \frac{V}{A} \times \frac{273}{273+T} \times \frac{12}{44}$$

$$SF_{N_2O} = \rho_2 \frac{dc}{dt} \times \frac{V}{A} \times \frac{273}{273+T} \times \frac{28}{44}$$

...where SF_{CO_2}, SF_{N_2O} stand for CO_2 flux in mg $C{\cdot}m^{-2}{\cdot}h^{-1}$ and for N_2O flux in μg $N{\cdot}m^{-2}{\cdot}h^{-1}$; ρ_1, ρ_2 for CO_2 and N_2O density under the standard conditions, respectively; *dc/dt* for temporal increase in CO_2 and N_2O concentration in the chamber headspace; *V* for effective headspace volume of the chamber (0.0168 m^3); *A* for the soil area covered by the chamber (0.14 m^2); and *T* for air temperature inside the chamber.

Soil C and N stock were calculated as follows:

$$SCS=BD\times SC\times D,\ SNS=BD\times ST\times D$$

...where SCS and SNS ($g{\cdot}cm^{-2}$) are the soil C and N stock; BD ($g{\cdot}cm^{-3}$) is soil bulk density; SC and SN ($g{\cdot}kg^{-1}$) are the concentration of SOC content and total N content; D (cm) is soil depth.

GWP Calculation

$$GWP = GWP_{fertilizer} + GWP_{pesticides} + GWP_{agriculture\ machinery} + GWP_{seed\ production} + GWP_{\Delta SOC} + GWP_{N_2O}$$

There are only 3-year N_2O and CO_2 emission data. The mean 3-year data was used to estimate the long-term $GWP_{N_2O\ and\ CO_2}$. $GWP_{fertilizer,\ agriculture\ machinery\ and\ seed\ production}$ were based on the C equivalents referred to by West and Marland [26].

$$GWP_{\Delta SOC} = SOC_{1985} - SOC_{2013} \text{ for cropland and grassland,}$$
$$GWP_{\Delta SOC} = SOC_{2000} - SOC_{2013} \text{ for forest}$$
$$GWP_{N_2O} = 298\times N_2O\times 12/44$$

Statistical Analyses

The differences in change of SCS (soil carbon stock), SNS (soil nitrogen stock), gas fluxes, and GWP across cropland, grassland, and forest were tested with statistical procedure of Origin 8 software at a significance level of 0.05. Correlations between GWP and ΔTSC (total soil carbon change), ΔTSN (total soil nitrogen change), CO_2, and N_2O emissions were analyzed using Excel 2010 software.

Results

Soil Bulk Density, Water Content, and Cand N Content

Mean data for soil density, water content, soil C and N content, determined in the soil from different depths taken from cropland, grassland, and forest land, are given in Table 1. Bulk density and water content generally decreased upon conversion from agricultural land to grassland or forest at the same depth, when compared to cropland. The average decrease in bulk density following conversion to grassland was 3.8% (n=5) and that of forest 1.6% (n=4) without 60-80 cm. The average water content was decreased by 24.1% and 15.4% upon conversion of agricultural land to grassland and forest, respectively. The total soil C and N in grassland increased by 51.1% and 28.4% at 28 y after conversion, and decreased by 7.2% and 5.2% at 14 y following conversion to forest. The depth to which soil samples are taken can significantly influence estimates of soil bulk density, water content, and total C and N contents. All these data decreased with soil depth.

CO_2 and N_2O Emissions

Soil CO_2 fluxes integrated over time was similar in all three land-use systems (Fig. 1). The CO_2 flux rates were low in January/February, but increased throughout May to September in conjunction with plant growth and a higher growing season temperature. The average CO_2 flux from 2006 to 2008 was 39.8, 46.7, and 40.9 mg CO_2-$C{\cdot}m^{-2}{\cdot}h^{-1}$ in cropland, grassland, and forest. The cumulative soil CO_2 emission per year was highest in grassland (4033 mg CO_2-$C{\cdot}ha^{-1}$), followed by forest (3537 mg CO_2-$C{\cdot}ha^{-1}$), and cropland (3443 mg CO_2-$C{\cdot}ha^{-1}$).

The average N_2O fluxes in cropland, grassland, and forest were 5.5, 7.9, and 1.3 μg N_2O-$N{\cdot}m^{-2}{\cdot}h^{-1}$. There were some extreme peaks in cropland (July/August, 2006, May, 2007), but N_2O flux on other dates was even lower in cropland than grassland. Forest land in general had the lowest N_2O flux during the three years measured (Fig. 1).

Changes in Total Soil C and N

For each of the three categories of land use considered (cropland, grassland, and forest), land use significantly affected the change in total soil C stock (TSC) and N stock

Table 1. Soil bulk density, water content, and total C and N from three soil plots, respectively.

Land use	Depth (cm)	Bulk density ($g \cdot cm^{-3}$)	Water content (%)	C ($g \cdot kg^{-1}$)	N ($g \cdot kg^{-1}$)
Cropland	0-20	1.09±0.00	28.40±0.30	34.15±0.76	2.45±0.05
	20-40	1.23±0.04	31.54±1.01	23.84±1.62	1.52±0.14
	40-60	1.30±0.01	29.48±0.30	15.73±0.34	0.82±0.07
	60-80	1.30±0.03	28.04±0.21	11.97±0.23	0.67±0.07
	80-100	1.35±0.01	27.94±.027	10.52±0.24	0.55±0.00
Grassland	0-20	0.98±0.04	17.91±0.27	43.46±0.67	3.48±0.02
	20-40	1.22±0.02	25.41±0.27	33.46±0.58	2.55±0.09
	40-60	1.26±0.03	25.85±0.36	21.87±0.07	1.53±0.05
	60-80	1.24±0.03	27.37±0.26	14.65±0.71	0.91±0.10
	80-100	1.36±0.01	26.40±0.21	10.09±0.75	0.61±0.07
Forest	0-20	1.11±0.02	17.08±0.51	29.50±1.13	2.10±0.10
	20-40	1.22±0.06	22.69±0.45	23.67±0.44	1.51±0.04
	40-60	1.27±0.02	23.68±0.36	16.95±0.75	0.91±0.17
	60-80	1.35±0.01	22.95±0.53	11.52±0.62	0.56±0.02
	80-100	1.33±0.02	24.01±0.29	9.54±0.47	0.50±0.01

(TSN) to 100 cm (Fig. 2). On average, the changes in TSC of the entire 100 cm profile were -523, 1722, and -239 $kg \cdot ha^{-1} \cdot y^{-1}$ in cropland, grassland, and forest, TSN being -83, 170, and -46 $kg \cdot ha^{-1} \cdot y^{-1}$, respectively.

There was a significant increase in change of soil C stock (SCS) and soil N stock (SNS) in the upper 20 cm of the soil profile after 28 y cultivation in cropland (Fig. 3). However, changes in SCS and SNS tended to decrease marginally in the 20-100 cm layer. The deeper the sampling depth, the smaller the change in SCS and SNS. After the conversion from agricultural land to grassland, the changes in SCS and SNS were larger than those in cropland and forest (with the exception of the 40-60 cm layer), and showed a significant positive increase (Fig. 3). However, the changes in SCS and SNS were nevertheless larger in forest compared to unchanged cropland.

Global Warming Potential (GWP)

The GWP of the cropland (717 kg CO_2-C equivalents $ha^{-1} \cdot y^{-1}$) was significantly the highest, followed by the forest and grassland at -324 and -1667 kg CO_2-C equivalents $ha^{-1} \cdot y^{-1}$, respectively (Table 2). The main difference in GWP across land use was attributable to differences in changes in

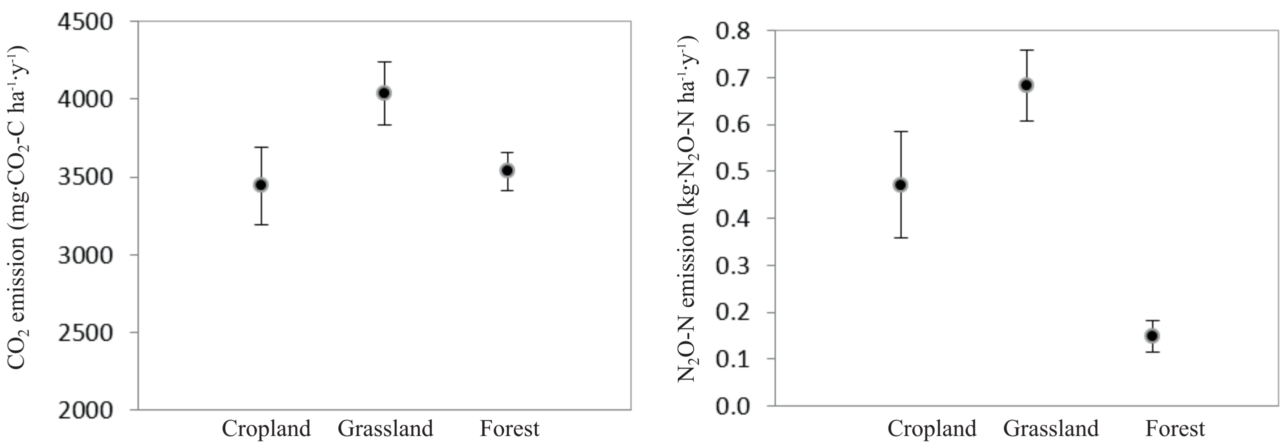

Fig. 1. Soil CO_2 and N_2O emissions from cropland, converted to grassland for 29 years and forest for 14 years. Bars are ±standard deviation.

Table 2. Estimated net global warming potential (GWP) (kg CO_2-C equivalents $ha^{-1}\cdot yr^{-1}$).

GWP components	NPK	GL	PL
Agricultural production[a]			
N fertilizer	68	-	-
P fertilizer	7	-	-
K fertilizer	14	-	-
Seed	20	-	-
Pesticides	15	-	-
Machinery	69	-	-
Total	194	-	-
Pine fix C[b]	-	-	-575
△Soil C[c]	523±197	-1722±176	239±98
Soil N_2O[d]	38±6	55±3	12±1
GWP[e]	755±192a	-1667±175c	-324±99b

[a]Carbon cost associated with crop production
[b]C fixed by pine biomass
[c]△Soil C = SOC_{1985}–SOC_{2013} for cropland and grassland;
△Soil C = SOC_{2000}–SOC_{2013} for forest
[d]GWP (kg CO_2-C equivalents $ha^{-1}\cdot yr^{-1}$) = 298 × N_2O × 12/28
[e]GWP = agricultural production + Pine fix C+△Soil C+N_2O
a, b, and c mean statistically siginificant at p<0.05.

SOC (ΔSOC), agricultural production, N_2O emission, and pine fixed-C. The ΔSOC contributed 69%, -100%, and 74% of GWP in cropland, grassland, and forest system, respectively. N_2O emissions accounted for 5%, -3%, and -4%, correspondingly.

The correlation analysis between gas emission, changes in TSC, TSN, and GWP is shown in Fig. 4. There was a significant positive relationship between change in CO_2 and GWP (R^2=0.7835; significant at 1% significance level), and between change in N_2O and GWP (R^2=0.5496; significant at 5% significance level). No significant relationship was found between soil total C and N stock (TSC and TSN) and GWP.

Discussion

C and N Changes Following Conversion from Agricultural Land to Grassland

Following conversion of cropland to grassland for 28 y, soil C and N content increased significantly (Table 1). This is because that grassland contains a large above-ground biomass of 1-3 $t\cdot C\cdot ha^{-1}$ and a higher root and shoot ratio compared to cropland [27]. Thus, a greater proportion of the root organic C was retained in soil and large amounts of above-ground litter returned to soil without annual removal through harvest. Moreover, the new material input is easy to decompose and therefore stimulates the C cycle in grassland system [28]. In our study, the highest emission of CO_2 and N_2O occurred in grassland and represented an increase of 17% and 40% compared to cropland (Fig. 1). Grass develops extensive root systems [10] and a C input of 3.15 $t\cdot C\cdot ha^{-1}$ (about 12 times to cropland) contributed to SOC accumulation. The present results show that the average rates of soil C stock ranged from 87 to 711 $kg\cdot C\cdot ha^{-1}\cdot y^{-1}$ throughout the soil profile (0-80 cm). Our results were in accordance with a maximum SOC accumulation rate of 1100 $kg\cdot C\cdot ha^{-1}\cdot y^{-1}$, previously observed in the surface 300 cm [29]. Soil sampling depth influenced the magnitude of change in soil C stocks after conversion from cropland to grassland. The deeper the sampling depth, the less effect of the grass on soil C stocks [8]. These data showed that grass could cause substantial C accumulation up to 80 cm depth, but this contribution decreased by 100 cm layer. Moreover, the change in soil N stock showed the same trend as C stock after conversion from agricultural land to grassland.

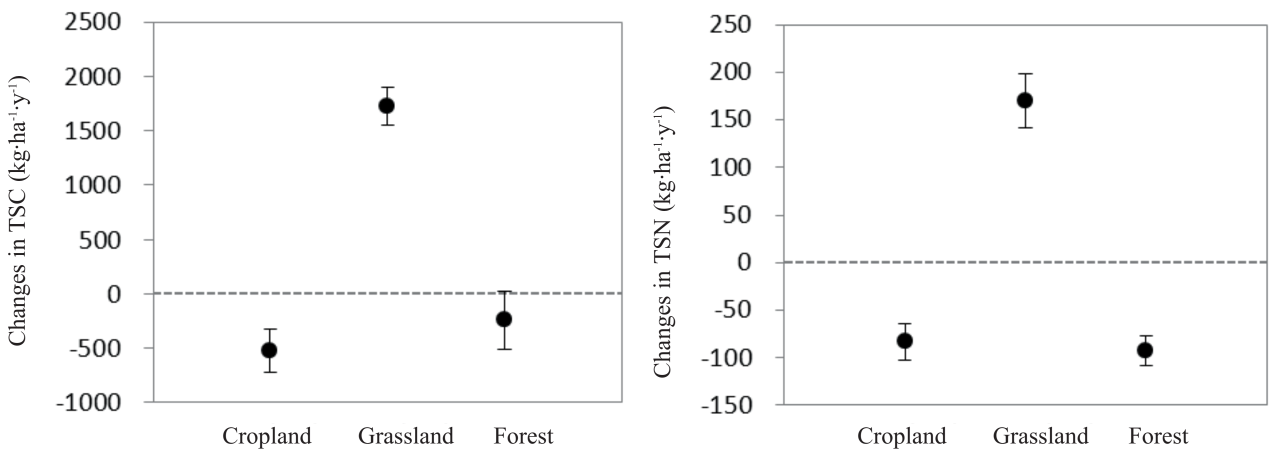

Fig. 2. Influence of conversion from cropland to grassland (28 y) and forest (14 y) on changes in TSC and TSN at 100 cm layer. The error bars are the standard errors of the mean.

C and N Changes Following Conversion from Agricultural Land to Forest

The results of the present study showed that afforestation of cropland did not lead to increased C and N content in the soil over 14 y in the full 100 cm profile (Table 1). This is in agreement with several studies in boreal zones after conversion from agricultural land to forest, as discussed in the review by Laganiere et al. [19]. Conversion from cropland to forest implies that the annual cycle of cultivating and harvesting crops is replaced by the much longer forest cycle. In the forest system, the balance of C and N input and output of the cropland system is broken [19]. The lower soil C and N input occurs due to a smaller forest biomass and low rate of litterfall [19, 30]. In addition, the slower decomposition rate in the boreal zone is a major factor inhibiting C and N input [31]. Hence, the present result is supported by previous observations in which soil carbon initially decreased during the first 12 y before gradual recovery and accumulation of soil carbon occurred [24].

In the present study, CO_2 emission per year in forest (3.5 g CO_2-C ha^{-1}·y^{-1}) was comparable to cropland (3.4 g CO_2-C ha^{-1}·y^{-1}, Fig. 1). The CO_2 emission measurement included root respiration and soil respiration. The relative large pine root biomass contributes more CO_2 respired [32]. The return of C was larger from pine (1.36 t·ha^{-1}) than cropland (0.27 t·ha^{-1}) (data not shown). All of the above favor the emission of CO_2 in the forest. Furthermore, the conversion of cropland to forest modifies the quality and quantity of litter inputs and soil microbial and faunal communities [19, 33]. In contrast, N_2O emissions per year were lower in forest (0.1 kg N_2O-N·ha^{-1}) than cropland (0.5 kg N_2O-N·ha^{-1}) in our study. As we know, N_2O emissions are mainly associated with nitrogen turnover in natural soil. Human activities intensify the process through N fertilizer application

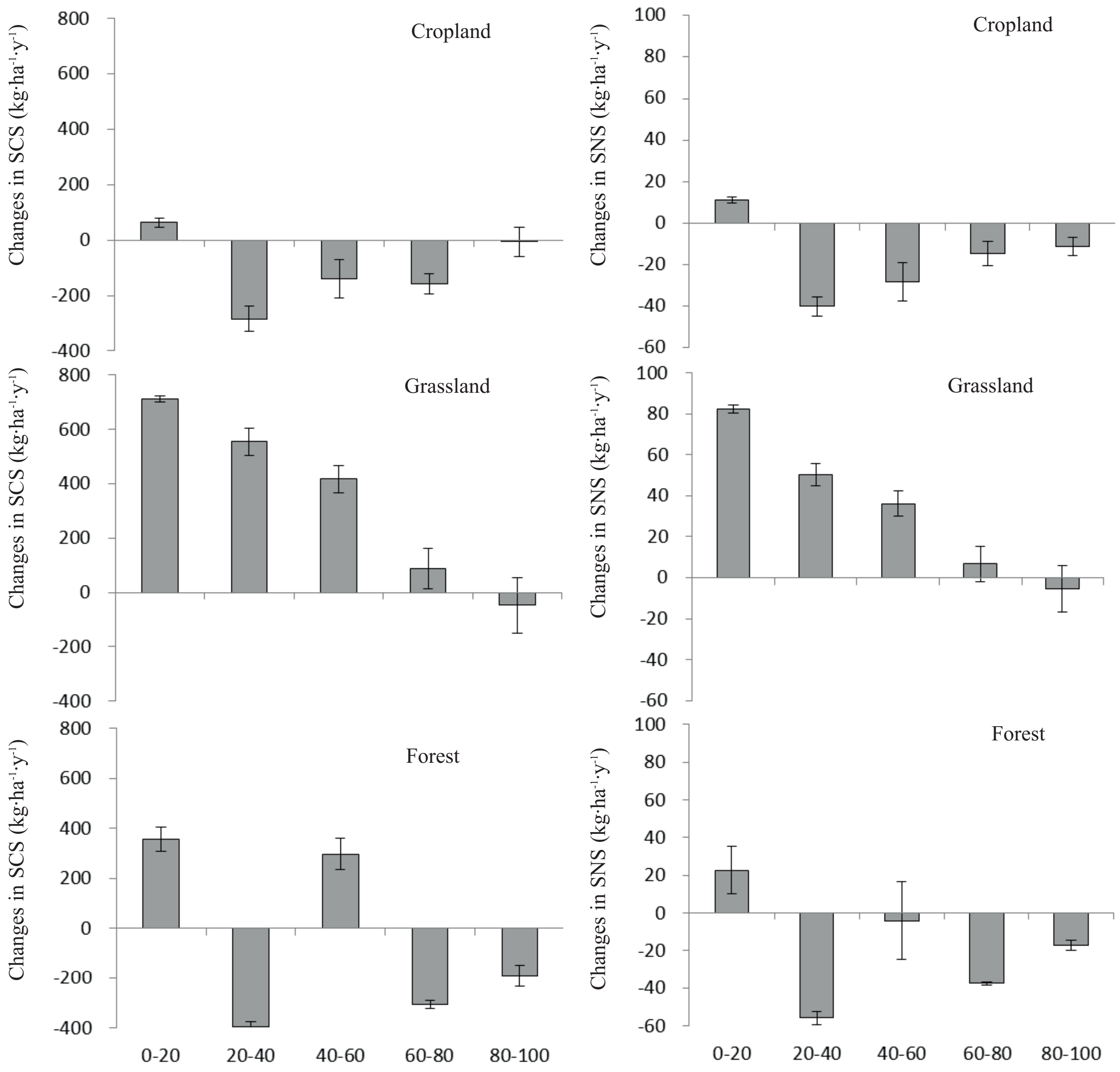

Fig. 3. Influence of conversion from cropland to grassland (28 y) and forest (14 y) on changes in SCS and SNS at different depth layer. The error bars are the standard errors of the mean.

and soil management [2, 34]. After conversion of cropland to forest, there was little human activity to provoke N_2O emissions. At the same time, our results were within the value reported by Ullah et al. [35], who researched N_2O emissions in three forest types in eastern Canada.

Over a 14-year conversion from cropland to forest, there was no significant difference in soil C and N contents compared to cropland. However, the change in SCS and SNS of the entire 100 cm layer was less in forest (54%) compared to cropland (Fig. 2). This is due, first of all, to the high NPP of pine, which increases C inputs to soil [36]. Second, the lack of tillage operations reduce disturbance and provide better protection of soil organic carbon against decomposition [37]. Third, the recalcitrance of C inputs is greater in forest than cropland [38]. All these reasons contributed to the observed change. Furthermore, the deeper root system in pine induced a change in SCS in the 80-100 cm layer, not seen in cropland.

GWP after Conversion from Cropland to Grassland and Forest

Agricultural production, ΔSOC, N_2O emission, and pine C fixed as biomass were used to estimate the GWP in each of the three land use systems (Table 2). In northeast China rain-fed agricultural systems, the CH_4 emissions are very low at < 2 g·ha^{-1} [39]; CH_4 emission was therefore not considered in this study. However, the energy used for farming operations such as fertilizer production, seed, pesticides, and machinery was included as indicated in reports of Qiao et al. [34] and Thelen et al. [40]. ΔSOC was calculated as the change in C between 1985 and 2013 for cropland and grassland, and between 2000 and 2013 for forest.

The results in this study show that ΔSOC was the dominant contributor to the GWP across three systems. In the 100 cm soil profile, C generally increased following conversion from agricultural land to grassland and forest, which is consistent with changes observed for surface soils following afforestation in northeast China [24] and permanent grassland conversion [41]. However, the present results showed that GWP was positively related to CO_2 and N_2O emissions, but not to ΔTSC and ΔTSN (Fig. 4). These data affirm that changing CO_2 and N_2O emissions through conversion of cropland to grassland and forest is a major consideration toward mitigating GWP in these soils.

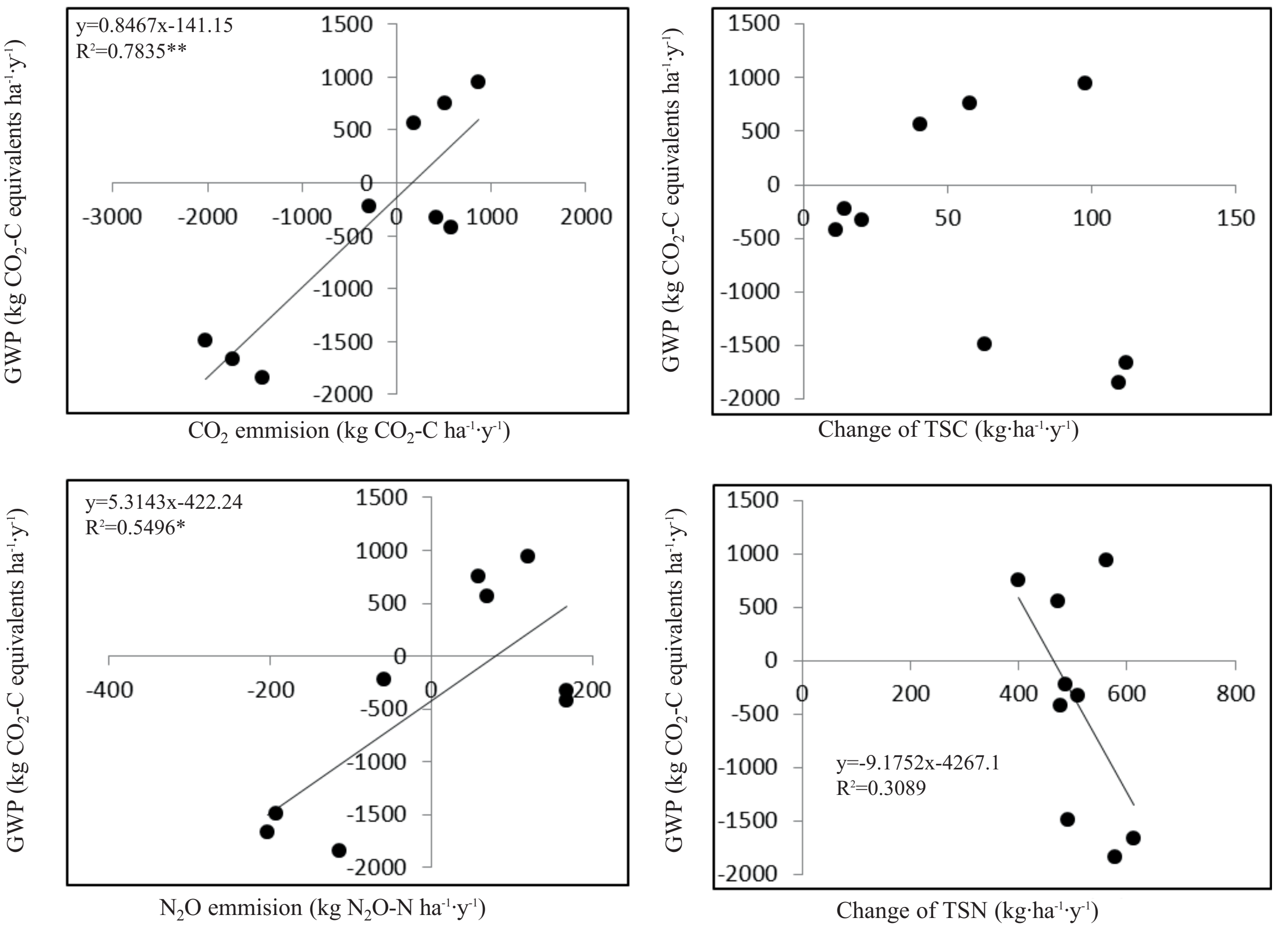

Fig. 4. The relationship between GWP and CO_2, N_2O, changes in TSC and TSN after conversion from cropland to grassland (28 y) and forest (14 y).

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References

1. BARRETT C.B. Measuring Food Insecurity. Science **327**, 825, **2010**.
2. KIRSCHBAUM M.U.F., SAGGAR S., TATE K.R., GILTRAP D.L., AUSSEIL A.G.E. Comprehensive evaluation of the climate-change implications of shifting land use between forest and grassland: New Zealand as a case study. Agr. Ecosyst. Environ. **150**, 123, **2012**.
3. SOLOMON S., QIN D., MANNING M., CHEN Z., MARQUIS M., AVERYT K.B., TIGNOR M., MILLER H. L. IPCC. Summary for policy makers. In: the TPSBCoWGIt, Climate FARotIPo, Change, editors. Climate Change ed. Cambridge University Press, Cambridge, United Kingdom and New York. pp. 1-18, **2007**.
4. JOBBÁGY E.G., JACKSON R.B. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecol. Appl. **10**, 423, **2000**.
5. SHI S., ZHANG W., ZHANG P., YU Y., DING F. A synthesis of change in deep soil organic carbon stores with afforestation of agricultural soils. Forest Ecol. Manag. **296**, 53, **2013**.
6. MCKINLEY D.C., RYAN M.G., BIRDSEY R.A., GIARDINA C.P., HARMON M.E. A synthesis of current knowledge on forests and carbon storage in the United States. Ecol. Appl. **21**, 1902, **2011**.
7. POST W.M., KWON K.C. Soil carbon sequestration and land-use change: processes and potential. Global Change Biol. **6**, 317, **2000**.
8. GUO L.B., GIFFORD R.M. Soil carbon stocks and land use change: a meta analysis. Global Change Biol. **8**, 345, **2002**.
9. VESTERDAL L., RITTER E., GUNDERSEN P. Change in soil organic carbon following afforestation of former arable land. Forest Ecol. Manag. **169**, 137, **2002**.
10. ZHANG K., DANG H., TAN S., CHENG X., ZHANG Q. Change in soil organic carbon following the 'Grain-for-Green' programme in China. Land Degrad. Dev. **21**, 13, **2010**.
11. SMITH P. Land use change and soil organic carbon dynamics. Nutr. Cycli. Agroecosystems. **81**, 169, **2008.**
12. ARORA V.K., BOER G.J. Uncertainties in the 20th century carbon budget associated with land use change. Global Change Biol. **16**, 3327, **2010**.
13. FORSTER P., RAMASWAMY V., ARTAXO P., BERNTSEN T., BETTS R. Changes in atmospheric constituents and in radiative forcing. Cambridge, United Kingdom: Cambridge University Press. pp. 129-234, **2007**.
14. SAGGAR S., TATE K.R., GILTRAP D.L., SINGH J. Soil-atmosphere exchange of nitrous oxide and methane in New Zealand terrestrial ecosystems and their mitigation options: a review. Plant Soil **309,** 25, **2008**.
15. SMITH P., MARTINO D., CAI Z., GWARY D., JANZEN H. Greenhouse gas mitigation in agriculture. Phil. Trans. R. Soc. B. **363**, 789, **2008**.
16. SMITH P., MARTINO D., CAI Z.C., GWARY D., JANZEN H. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agr. Ecosyst. Environ. **118**, 6, **2007**.
17. KELLIHER F.M., CLARK H., LI Z., NEWTON P.C.D., PARSONS A.J. A comment on scaling methane emissions from vegetation and grazing ruminants in New Zealand. Funct. Plant Biol. **33**, 613, **2006**.
18. KIRSCHBAUM M.U.F., BRUHN D., ETHERIDGE D.M., EVANS J.R., FARQUHAR G.D. A comment on the quantitative significance of aerobic methane release by plants. Funct. Plant Biol. **33**, 521, **2006**.
19. LAGANIERE J., ANGERS D.A., PARE D. Carbon accumulation in agricultural soils after afforestation: a meta-analysis. Global Change Biol. **16**, 439, **2010**.
20. IPCC. Third Assessment Report. Climate Change 2001: Cambridge University Press, pp. 231, **2001**.
21. MEKI M.N., KEMANIAN A.R., POTTER S.R., BLUMENTHAL J.M., WILLIAMS J.R. Cropping system effects on sorghum grain yield, soil organic carbon, and global warming potential in central and south Texas. Agri. Systems **117**, 19, **2013**.
22. PAUSTIAN K.E., ELLIOTT T., KILLIAN K., CIPRA J., BLUHM G. Modeling and regional assessment of soil carbon: a case study of the Conservation Reserve Program.; Lal R MK, editor. Madison, WI: SSSA Special Publ. pp. 315-318, **2001**.
23. FAO. Food and Agriculture Organization. Access at WWW. fao.org. **2010**.
24. WANG C.M., OUYANG H., SHAO B., TIAN Y.Q., ZHAO J.G. Soil Carbon Changes Following Afforestation with Olga Bay Larch (*Larix olgensis* Henry) in Northeastern China. J. Integr. Plant Biol. **48**, 503, **2006**.
25. XING B.S., LIU X.B., LIU J.D., HAN X.Z. Physical and chemical characteristics of a typical Mollisol in China. Commun. Soil Sci. Plan. **35**, 1829, **2004**.
26. WEST T.O., MARLAND G. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agr. Ecosyst. Environ. **91**, 217, **2002**.
27. VERCHOT L., KRUG T., LASCO R.D., OGLE S., YUE L.Y. Chapter 6, Grassland, pp. 256, **2006**.
28. SHANG Z. H., CAO J. H., GUO R. Y., LONG R. J., DENG B. The response of soil organic carbon and nitrogen 10 years after returning cultivated alpine steppe to grassland by abandonment or reseeding. Catena. **119**, 28, **2014**.
29. GEBHART D.L., JOHNSON H.B., MAYEUX H.S., POLLEY H.W. The CRP increases in soil organic carbon. J. Soil Water Conserv. **49**, 488, **1994**.
30. WANG C.M. Impact of converting cropland to forest on the carbon balance and cost-benefit assessment. Beijing: Chinese Academy of Science, pp. 136-138, **2005**.
31. VAVΓVA P., PENTTILË T., LAIHO R. Decomposition of Scots pine fine woody decris in boreal conditions: Implications for estimating carbon pools and fluxes. Forest Ecol. Manag.. **257**, 401, **2009**.
32. ORAL H. V., GUNEY M., KUCUKER M. A., ONAY T. T., COPTY N. K., MATER B., YENIGUN O. The impact of hazelnuts in land-use changes on soil carbon and *in situ* soil respiration dynamics. J. Environ. Manag. **129**, 341, **2013**.
33. BOUWMAN A.F., LEEMANS R. The role of forest soils in the global carbon cycle. Soil Science Society of America, Madison, WI. pp. 431, **1995**.

34. QIAO Y.F., MIAO S.J., HAN X.Z., YOU M.Y., ZHU X. The effect of fertilizer practices on N balance and global warming potential of maize-soybean-wheat rotations in Northeastern China. Field Crops Research, **161**, 98, **2014**.
35. ULLAH S., FRASIER R., KING L., PICOTTE-ANDERSON N., MOORE T. R. Potential fluxes of N_2O and CH_4 from soils of three forest types in Eastern Canada. Soil Biol. Biochem. **40**, 986, **2008**.
36. IMHOFF M.L., BOUNOUA L., RICKETTS T., LOUCKS C., HARRISS R. Global patterns in human consumption of net primary production. Nature **429**, 870, **2004**.
37. SIX J., ELLIOTT E.T., PAUSTIAN K. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol. Biochem. **32**, 2099, **2000**.
38. CERLI C., CELI L., JOHANSSON M.B., KOGEL-KNABNER I., ROSENQVIST L. Soil organic matter changes in a spruce chronosequence on Swedish former agricultural soil I. Carbon and lignin dynamics. Soil Sci. **171**, 837, **2006**.
39. DING W.X., WANG Y., WANG D. Emission of CO_2 and CH_4 from black soil in northeast china. J. Agro-Environ. Sci. **22**, 720, **2003**.
40. THELEN K.D., FRONNING B.E., KRAVCHENKO A., MIN D.H., ROBERTSON G.P. Integrating livestock manure with a corn-soybean bioenergy cropping system improves short-term carbon sequestration rates and net global warming potential. Biomass Bioenerg. **34**, 960, **2010**.
41. FISHER M.J., RAO I.M., AYARZA M.A. Carbon storage by introduced deep-rooted grasses in South American savannas. Science **371**, 236, **1994**.