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Ecosystem-scale carbon allocation among different land uses: implications for carbon stocks in the Yellow River Delta

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Abstract. The reclamation area of the Chinese Yellow River Delta (YRD) has experienced frequent land use changes in recent decades. The consequence of such land use changes on the stocks and allocation of ecosystem-scale carbon is not known. Here, we assessed carbon stocks and allocation of four representative land uses in the YRD area: (1) purple alfalfa (LAL), (2) reed and *Aeluropus littoralis* (RAE), (3) cotton (ECO), and (4) Chinese tamarisk (CTA). The results showed that the overall carbon stocks, and carbon stocks of aboveground, litter, roots, and soil were notably different among different land uses. The native CTA land had the largest overall carbon stock (belowground and aboveground) and had the strongest potential to allocate the carbon to the soil carbon pool (95.72%), followed by the natural grassland (RAE). Alfalfa grassland (LAL) also had a large carbon stock due to its large aboveground biomass, litter, and roots, but the relative allocation proportion of soil carbon stock was lower than that of the other land uses examined. Cotton (ECO) had the lowest soil carbon and total carbon stocks among four land uses. In combining our data on the carbon pool with changes of land use in the YRD area, we argued that land reclamation in the YRD area was likely to turn this area from a carbon sink to carbon source with the release of soil organic carbon. Therefore, cautions should be taken to reduce carbon release, if the reclaimed land be used to plant crops.

Key words: carbon allocation; carbon pools; land use; reclamation; soil organic carbon.

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Introduction

The biogeochemical cycle of carbon in terrestrial ecosystems plays a critical role for mitigating or exacerbating global greenhouse effect (Fu et al. 2010, Liu et al. 2011, Zhang et al. 2013). Many factors impact the biogeochemical cycle of soil organic carbon (SOC) and consequently impact the distribution and stock of SOC (Bubier et al. 2003, Eze et al. 2017). There is a broad agreement that land use changes are major driving factors for the balance of SOC stock, global carbon cycle, and soil services in terrestrial ecosystems (Houghton et al. 1999, Poeplau et al. 2011).

Land uses can alter the input rates, decomposition, and turnovers of organic matter (Zhang et al. 2013, Stumpf et al. 2018). The conversions of vegetation by land uses also affect soil carbon stocks, which can lead to a large amount of carbon exchange (Bolin and Sukumar 2000, Mendham et al. 2003). Numerous studies have shown that the conversion of native forest or pasture to cropland, inappropriate cultivation management, and other disturbance have caused a soil carbon loss of more than 40 Pg C (Smith 2008, Fu et al. 2010), accounting for 20–42% of total soil carbon in the terrestrial systems (Johnson and Curtis 2001, DeGryze et al. 2004). The conversion of cropland to forest and pasture or improving soil management can increase soil carbon sequestration by up to 51% (Watson et al. 2000, Conant et al. 2001, Eaton et al. 2008). Soil may become a carbon sink or a carbon source after the conversion of forest to pasture, depending on the type of pasture, regional climate, sampling depth, and management measures (Franzluebbers et al. 2000, Post and Kwon 2000, Guo and Gifford 2002). The inappropriate cultivation management, such as intensive arable farming and frequent conversation of land use, can affect SOC dynamics due to the decline in organic residues returned to the soil (Caravaca et al. 2002, Jin et al. 2010, Adegaye et al. 2019). However, the conservation tillage management of less tillage, no-till with straw retention, and the use of mulch can contribute to the transformation of soil organic matter, the improvement of carbon stock due to less mineralization, and the promotion of sustainable agriculture development (Roldán et al. 2003, Kan et al. 2020).

The storage capacity of soil carbon is an important index of soil quality and soil service, which can be strongly influenced and regulated by land uses. Wetland ecosystems account for 10% of the global terrestrial ecosystem carbon pool (IPCC 2001). Coastal wetlands are important wetland ecosystem and precious land resources for agriculture in many countries (Li et al. 2014). These wetlands also play a significant role in carbon sequestration in coastal areas worldwide (Chmura et al. 2003, Zhang et al. 2015). In China and other developing countries, reclamation has been a common practice for agricultural uses in coastal wetlands for many years (Cheng et al. 2009, Fernández et al. 2010, Zhang et al. 2017), which is effective for relieving population pressure and ensuring food safety (Li et al. 2014).

The Yellow River Delta (YRD) is one of the largest natural river delta areas in China. It is also one of the most representative river wetland ecosystems in the world (Yang et al. 2013, Gao et al. 2014). The wetlands in the YRD have been reclaimed for gaining new arable land since the 1950s (Zhang et al. 2017). In recent decades, land use change was frequent in the reclamation area of the YRD due to the widely occurred secondary salinization, which has been recognized as a challenge to cultivation and a threat to food production and the environment (Fang et al. 2005, Zhang et al. 2011). At present, multiple patterns of crop–pasture–native vegetation have been formed in the reclamation area of the YRD (Hughen et al. 2004, Piao et al. 2009). The impacts of these different patterns of land use on carbon stocks, however, have largely been overlooked.

What was the carbon dynamic (sink or source) after the large-scale reclamation in the YRD? How much was the effect of different land uses on the carbon stocks and allocation for the aboveground and belowground? We hypothesize that in the reclamation area of the YRD: (1) The carbon stocks and allocation are significantly affected by land use types and soil depth; and (2) the YRD area was likely an important carbon sink prior to the large-scale reclamation in the 1950s. The goal of this study was to quantify ecosystem-scale carbon stocks and allocation in both aboveground and belowground pools on four representative land uses in the YRD. Therefore, the status of carbon stocks and allocation under different land uses was investigated to test our hypothesis. Our objectives were to (1) study the effects of four representative land uses on carbon stocks in the reclamation area of the YRD; quantify the carbon allocation of aboveground, litter, roots, and soil under ecosystem scale; and (2) confirm the carbon dynamics (sink or source) after the large-scale reclamation in the YRD. Not only will this quantitative information obtained here may provide important implications for carbon dynamics at landscape and regional scales and in the cases when different land use patterns occur in the YRD, but it will also be crucial for developing effective approaches of land use management reducing CO_2 emission in the context of mitigating global climate change.

Materials and Methods

Site description

The study site is located in the reclamation area of the YRD (118°06′ E–120°00′ E, 37°15′ N–38°10′ N, with an elevation of 3–12 m), Dongying

City, situated at the northeast of Shandong Province, China (Fig. 1). The area has a semi-humid continental monsoon climate with an annual mean precipitation of 585 mm, of which 70% occurs between July and August. The evaporation is 1900–2000 mm. The mean air temperature is 12.1°C and the frost-free period is approximately 142 d. It is a flat floodplain with a plain slope in this site (Shi and Zhang 2003). As a newly formed estuarine delta, it has been undergoing extensive and rapid development about industry and agriculture over recent decades. Large area of grassland and wilderness has been cultivated with salt-tolerant crops and grass. Due to the recent reclamation, land use and land cover in this area changed frequently with the secondary salinization induced by human activities. Cotton is an important crop in the region, and purple alfalfa is the livestock green fodder. The dominant native species are *Phragmites australis* (Cav.) Trin. ex Steud., *Aeluropus littoralis* Gouan, and *Tamarix chinensis* Lour. *T. chinensis* has only sporadic distribution today due to human activities. The soil in the study site is generally coastal saline moisture soil with severe salinity and poor nutrient conditions (Table 1), which is similar to American soil classification of Fluvents (Gao et al. 2014). The salt content at the soil surface of 0–15 cm ranges from 0.4% to 1.5% (Shi and Zhang 2003).

The study site was selected based on local primary land uses and preexisting experimental setups in 2010 (Fig. 1). Four land use types within the same physiographical units were selected: (1) artificial leguminous grassland, purple alfalfa (*Medicago sativa*; LAL); (2) native grassland, reed and *Aeluropus littoralis* (*P. australis* and *A. littoralis*; RAE); (3) economic crop, cotton (*Gossypium* spp; ECO); and (4) native shrubland, Chinese tamarisk (*T. chinensis*; CTA). The alfalfa in the LAL field was first planted in 2001 by converting the native grassland. The alfalfa was harvested four times as green forage source (cut near the soil surface) every year in late May, early July, late August, and early October. No fertilizer was added to the LAL field during the experimental period. The cotton fields of ECO site were tilled conventionally, and cotton grow from early May to late September. The RAE and CTA are both native plant communities and were not cultivated or fertilized.

Experimental design and sampling method

In spring 2014, we established four 20 × 20 m plots as true replicates at each representative site of land uses shown above. The distance among four plots exceeded the spatial dependence (<13.5 m) of most soil chemical and microbial property variables (Mariotte et al. 1997, Wang et al. 2011). On each plot, four randomly selected sampling points of 1 × 1 m quadrats were set up to obtain the above- and belowground biomass, and soil samples. In total, we determined four plots as replicates with 16 quadrats in each type of land use, and 16 plots with 64 quadrats for our study. In the plots of four ecosystems (LAL, RAE, ECO, and CTA), the aboveground net primary production (ANPP) was estimated by peak live biomass method with annual productivity (Zhou et al. 2007, Ruppert and Linstädter 2014), which was at the peak growing biomass clipping all living tissues at ground level in four quadrats on each plot. The ANPP of shrub ecosystem in CTA was obtained as the total biomass of current-year branches and leaves (Li and Zhao 2017). The aboveground biomass for LAL was measured according to the production habit and was obtained by measuring the cumulative biomass harvested four times during the growing season between May and October. The biomass for ECO was made prior to mowing. The biomass at the RAE and CTA sites was measured by a single sampling in peak growing biomass period in mid-August when was the time of peak aboveground biomass in this site. Aboveground biomass of the herbaceous layer was obtained by clipping all biomass in four 1 × 1 m quadrats at ground level in each plot. For the shrub, we selected three of each large-, medium-, and small-sized shrubs, the biomass was obtained by clipping the whole plant or its portion, and then, the aboveground biomass per unit area was calculated according to the cluster proportion of the community. The litter samples were also collected from each 1 × 1 m quadrat, respectively.

In mid-August 2014, we further determined the root biomass for the LAL, RAE, and ECO sites by using an 8 cm diameter soil core sampler. Soil cores were sampled from four random locations to the depth of 100 cm within each 1 × 1 m quadrat established for vegetation sampling. For the CTA site, the same three clusters,

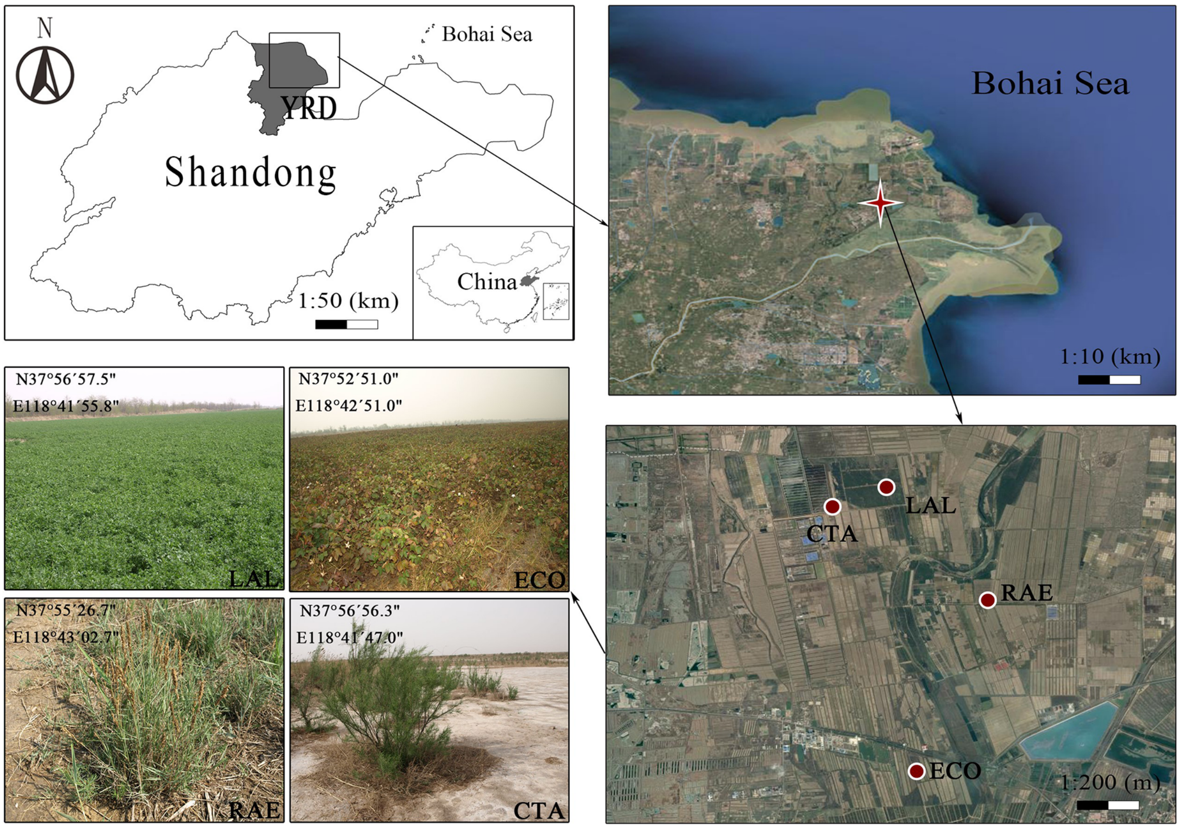

Fig. 1. Location of the study area in the Yellow River Delta (YRD) of the northeast estuarine area, China. Pictures on the left show the four plant communities that were selected for this study. Abbreviations are LAL, purple alfalfa; ECO, cotton; RAE, reed and *Aeluropus littoralis*; CTA, Chinese tamarisk.

Table 1. Soil physiochemical properties in 0–20 cm depth for the primary land uses investigated in the study.

Land uses	TN (g/kg)	AL-P_2O_5 (mg/kg)	AL-K_2O (mg/kg)	pH (H_2O 1:2.5)	EC (μS/cm)	Clay (%)	Silt (%)	Sand (%)
LAL	6.82	10.67	82.51	8.15	127.43	2.54	10.43	87.12
RAE	3.27	6.64	173.02	7.84	141.19	3.51	18.92	77.57
ECO	1.11	14.99	170.21	8.14	723.88	2.93	12.71	84.36
CTA	2.49	16.32	196.85	7.44	3964.1	2.37	10.26	87.37

Notes: TN, total nitrogen; AL-P_2O_5, available phosphorus; AL-K_2O, available potassium; EC, electrical conductivity. The particle size ranges of clay, silt, and sand are <0.002 mm, 0.002–0.02 mm, and 0.02–2 mm, respectively.

representing large, medium, and small shrubs, were selected to determine the root biomass. The root biomass per unit area was calculated according to the cluster proportion of the community.

Lastly, a separate group of soil samples were collected at the same quadrats as the plant biomass sampling by using a 3.8 cm diameter soil core sampler to determine the soil carbon distribution along the soil profile. Four soil cores from another random location of each quadrat were collected and mixed to create a representative soil sample and separated into 10-cm layers down to a depth of 100 cm.

Laboratory analysis

In the laboratory, samples of soil, plant biomass, litter, and roots were oven-dried at 70°C to constant weight (approximately 48 h). Roots in the soil cores, including both fine and coarse roots, were carefully picked up manually. All dried plant, soil, and root samples were crushed to pass through a 0.20-mm sieve to analyze organic carbon concentration and to calculate carbon stocks. Soil bulk density (BD) was determined in each layer in each quadrat by the 100-cm^3 ring cylinder method. The organic carbon for plant (aboveground biomass, litter, and root) and soil samples was measured by a modified Walkley-Black method (Nelson and Sommers 1982). During chemical analysis, all samples are measured by parallel and blank tests to ensure accuracy and precision. In brief, 0.5 g soil or 0.1 g plant samples were extracted with 5 mL of 1 N $K_2Cr_2O_7$ and 10 mL of concentrated H_2SO_4 at 150°C for 30 min, and then cooled at room temperature, followed by titration of the extracts with standardized $FeSO_4$. Organic carbon concentration was calculated, without a recovery factor, from the difference in $FeSO_4$ used between blank and soil solution.

Data analysis

The soil organic carbon density (SOCD, g/m^2) for each land use was calculated using the following formula (Zhou et al. 2007):

$$\mathrm{SOCD} = \sum D_i \times C_i \times \mathrm{OM}_i \times S$$

where D_i, C_i, OM_i, and S represent the soil BD, soil depth, SOC concentration, and cross-sectional area of soil core of the ith layer, respectively, and $i = 1, 2, 3, \ldots$, and 10.

One-way ANOVA was used to examine the effects of land uses on carbon stocks. Means of the main effect were compared using Duncan multiple-range procedure test at $P \leq 0.05$ for significance. All the statistical analyses were performed using the SPSS software, ver. 16.0 (SPSS, Chicago, Illinois, USA). All the figures were produced using Origin 10.0 (OriginLab, Northampton, Massachusetts, USA).

Results

Biomass and carbon stocks for different land uses

The aboveground and root biomass are generally significantly different among the four land uses ($P < 0.05$; Fig. 2 and Table 2). LAL had the largest aboveground and root biomass, and RAE and CTA had the lowest aboveground biomass and root biomass, respectively.

Aboveground net primary production and carbon stocks for root, litter, and soil all varied significantly among different land uses (Fig. 3a–d and Table 2). The largest ANPP and carbon stocks for roots were found in LAL, and the lowest was found in CTA. Aboveground net primary production for the LAL was 14.30-fold of that for the CTA. Also, the carbon stocks in the roots were generally 20-fold higher than those in the litter. For the integrated SOC stocks (0–100 cm), the largest was found in CTA (5520.96 g C/m^2), followed by RAE, and ECO had the lowest SOC stock of 3568.93 g C/m^2.

Allocation of carbon for different land uses

For individual land uses, SOC stocks generally decreased with the increasing of soil depth (ANOVA, $P < 0.05$), and were the largest in the top 10 cm for four land uses, except for the LAL

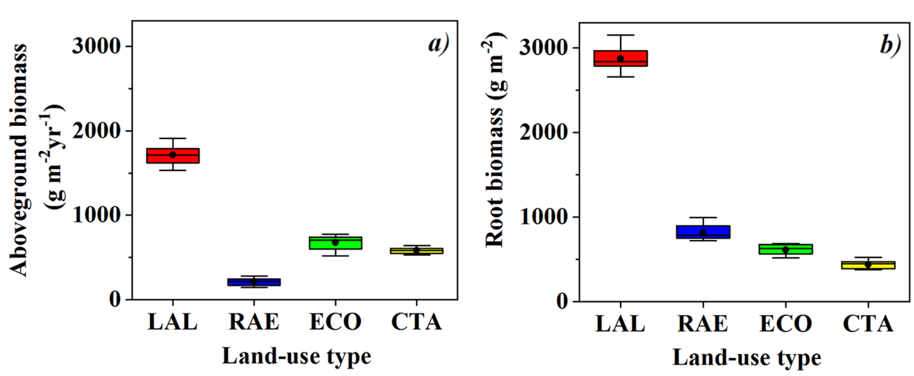

Fig. 2. (a) Aboveground and (b) root biomass (n = 16) for different land uses in the study area.

Table 2. The biomass and carbon stocks in aboveground, litter, roots, and soil for different land uses in the study area.

Land uses	Aboveground biomass ($g \cdot m^{-2} \cdot yr^{-1}$)	Root biomass (g/m^2)	Aboveground C ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Litter C ($g\ C/m^2$)	Root C ($g\ C/m^2$)	Soil C ($g\ C/m^2$)
LAL	1710.84 ± 65.71 a	2874.51 ± 64.52 a	769.88 ± 29.57 a	58.38 ± 7.54 a	1363.15 ± 19.38 a	3881.53 ± 94.88 c
RAE	210.75 ± 23.74 c	814.57 ± 59.74 b	102.57 ± 10.44 c	14.15 ± 1.25 b	381.10 ± 31.06 b	4334.26 ± 60.66 b
ECO	675.04 ± 54.18 b	611.64 ± 25.87 c	344.63 ± 28.63 b	7.39 ± 0.51 b	294.48 ± 17.29 c	3568.93 ± 45.99 d
CTA	583.64 ± 23.95 b	437.49 ± 26.79 d	53.85 ± 5.12 c	12.35 ± 0.99 b	181.06 ± 9.52 d	5520.96 ± 126.86 a

Note: Values (means ± standard error, n = 4) followed by different letters within columns are significantly different at $P < 0.05$ by ANOVA.

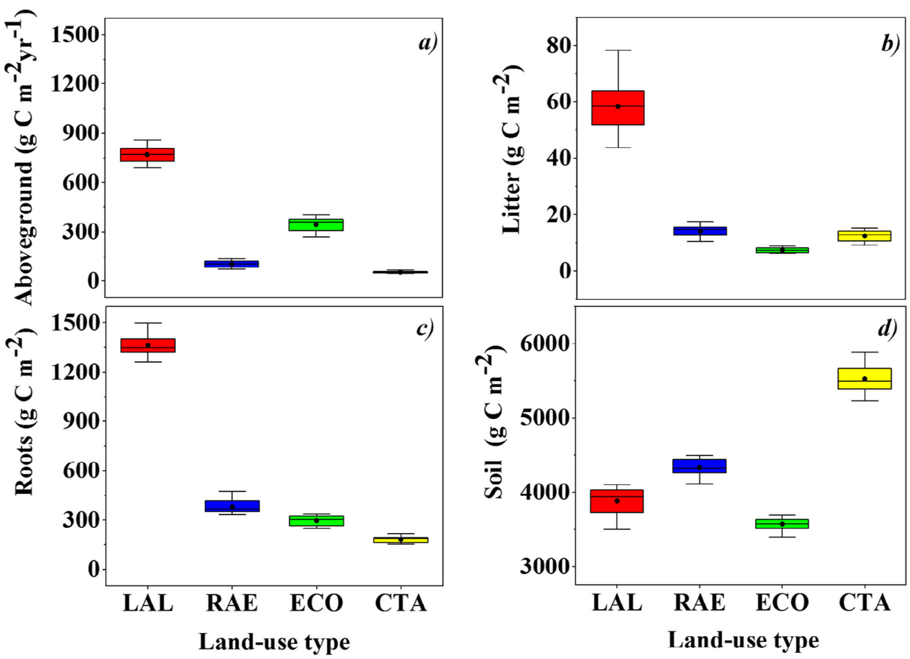

Fig. 3. Carbon stocks in (a) aboveground, (b) litter, (c) roots, and (d) soil for different land uses in the study area (n = 16). The soil carbon stock is to 100 cm depth.

where the highest appeared in the depth of 10–20 cm (Fig. 4 and Appendix S1: Table S1). For all four land uses studied, about half of the total SOC stocks were found in the top 30 cm of the soil profile.

Figs. 5, 6 show the allocation of carbon stocks between the aboveground pools (ANNP and litter) and the belowground pools (roots and soil). For all the four land uses, belowground carbon stocks are predominant (Fig. 5a and Appendix S1: Table S2) and account for 86% (LAL) to 98% (RAE) of the total carbon stocks (Fig. 6). The overall carbon stocks are the highest in the LAL and CTA sites, and lowest in the ECO site (Fig. 5b and Appendix S1: Table S2). For individual carbon pools, a majority of the ecosystem carbon is stored as SOC, regardless of the land use (Fig. 6). For LAL and RAE, roots amount for the second largest carbon pool, whereas for ECO and LAL, ANPP is the second largest.

Potential changes of carbon stocks after land use conversion

The land use conversion was accompanied by the dynamics of carbon stock (Table 3). It is helpful to increase the biomass carbon by the conversion of saline–alkali land or natural grassland to cultivated land, but largely lost the soil carbon

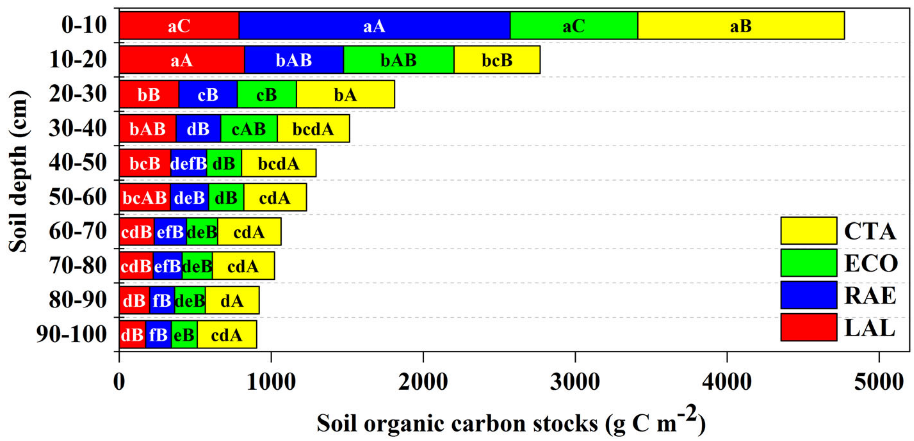

Fig. 4. Soil organic carbon stocks (g C/m^2) at different soil depths for different land uses. The different lowercase letters within soil depths and uppercase letters within land uses are significantly different at $P < 0.05$ by ANOVA ($n = 4$).

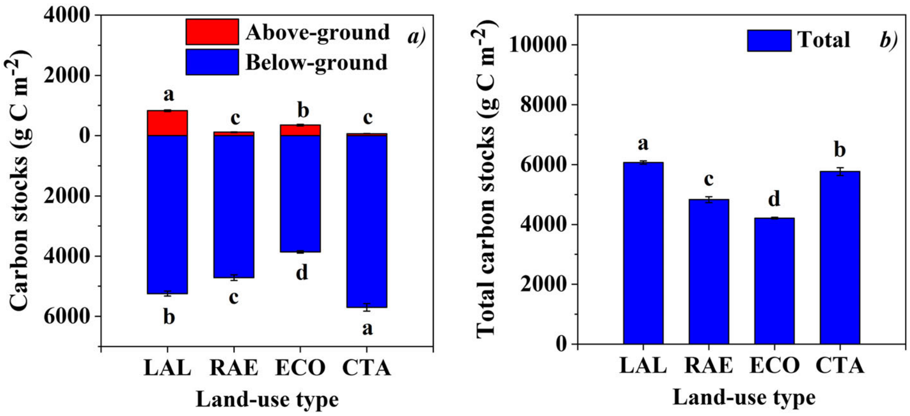

Fig. 5. (a) Above- and belowground carbon stocks and (b) total carbon stocks for different land uses in the study area. Vertical bars show standard errors of means ($n = 4$), and different letters indicate significant difference at $P < 0.05$ of ANOVA. (a) Aboveground refers to the sum of aboveground net primary production and litter carbon, belowground refers to the sum of root carbon and soil carbon; soil carbon stock is the sum of 0–100 cm depth; and (b) total refers to the sum of above- and belowground carbon stocks.

stock; the total carbon stock was finally decreased. According to the conversion area from 2000 to 2010 (Appendix S1: Table S3) and our study estimation of carbon stock, we estimated that up to 184.96 × 10^4 t C may have been released with the conversion of saline–alkali land to cultivated land in the YRD area during this period. The conversion of saline–alkali land to natural grassland, and natural grassland to cultivated land was accompanied by a moderate decrease in total carbon stocks (Table 3).

Discussion

The YRD, as a piece of young land, serves multiple ecological functions and has enormous economic potential for sustainable development (Gao et al. 2014). Developing comprehensive agriculture in the YRD was planned by the Chinese central government (Zhang et al. 2011), and the consequent large-scale agricultural production has been developed simultaneously with the policy. Anthropogenic activities in terms of

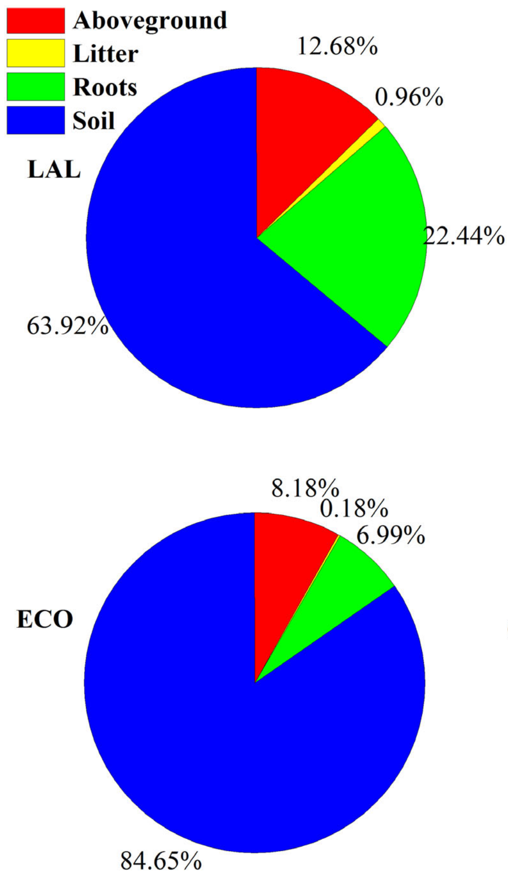

Fig. 6. The relative allocation (%) of carbon between the above- and belowground pools (n = 4) among different land uses in the study area.

Table 3. Potential changes of carbon stocks (10^4 t C) with the primary land use changes in the study area from 2000 to 2010.

Land use conversion	Aboveground	Roots	Litter	Soil	Total C stocks
Saline–alkali land to cultivated land	+34.64	+13.51	−0.59	−232.51	−184.96
Natural grassland to cultivated land	+3.39	−1.21	−0.09	−10.72	−8.64
Saline–alkali land to natural grassland	+0.28	+1.16	+0.01	−6.89	−5.43

Notes: "+" refers to the increase in carbon stock after land use conversion, and "−" refers to the decrease in carbon stock after land use conversion. Total C stocks refer to the sum of carbon stocks for aboveground, roots, litter, and soil organic carbon.

reclamation for arable land and land use conversion have contributed to accelerated land degradation and soil CO_2 emission. The need to demonstrate better land use type and reduce carbon loss is currently acknowledged. In this study, selecting four representative land uses as a case study, results of our study suggested that the overall carbon stocks and carbon stocks of aboveground, litter, roots, and soil were notably different among different land uses in the YRD area. Not surprisingly, we found soil stock was a major component of the overall carbon stocks as found in terrestrial ecosystems (Post and Kwon 2000, Lemenih et al. 2005, Fu et al. 2010). It is noteworthy that alfalfa grassland (LAL) was able to allocate a greater proportion of its carbon stocks to aboveground biomass, litter, and roots, whereas the relative allocation proportion of soil carbon stock was lower than that of the other land uses examined. This finding was in agreement with an earlier study conducted in an agro-pastoral ecotone of northern China, which reported that higher aboveground biomass productivity resulting from land use changes did not always support higher belowground carbon stocks (Zhou et al. 2007). Despite the promising productivity for the alfalfa field, the conversion of native grassland to alfalfa field should be treated with caution, as the duration of alfalfa has not been proved in the extreme event of secondary salinization. We also demonstrated most of the alfalfa fields were developed on new arable land from recent reclamation, which may not have sufficient amounts of SOC stock. It needs to be further verified over a longer temporal scale whether the alfalfa fields would facilitate both better productivity and soil carbon stock in the YRD.

The change of land use was assumed to be the most dynamic factor of SOC changes (Guo and Gifford 2002, Poeplau et al. 2011). Results of our study also showed that the land use composed of native shrub Chinese tamarisk (CTA) had the strongest potential to allocate the carbon stocks to soil (95.72%), followed by the natural grassland (RAE). The artificial grassland (LAL) allocated 64% of the total carbon to soil, which was the lowest proportion compared with other land uses, but its root carbon proportion (22%) was by far the highest among the four land uses studied. These results also confirmed that the major contributor to the carbon pool was soil. The strong allocation of carbon to soil by the Chinese tamarisk in the CTA site was likely due to the low rates of soil respiration and low mineralization rate of organic matter, which may lead to the accumulation of litter and the SOC accumulation (Jandl et al. 2007, Heckman et al. 2009). From the perspective of carbon sequestration, native vegetation would be most effective as it was able to preserve most of the carbon belowground. Studies at the regional scale confirmed that vegetation type affected SOC stock by controlling both the input and decomposition of carbon (Wiesmeier et al. 2019). The decrease in organic carbon inputs in the soil can reduce the microbial respiration (Cardoso et al. 2013, Trivedi et al. 2016), and the biological activity was modulated through soil organic matter, which quantity and quality of decided the mineralization rate of organic matter (Trivedi et al. 2016, Malik et al. 2018). The shrub ecosystem (CTA) was more resistant to the decomposition of organic carbon than that of crop land (Berg 2000, Jandl et al. 2007). The native grassland (RAE) was able to maintain a continuous cover of vegetation on the soil that facilitated organic matter input, which consequently increased the biological activity. Cotton (ECO) and purple alfalfa (LAL), on the other hand, would be least effective due to the fact that the carbon stocks of these two land uses were relatively small and only a small proportion of carbon was allocated to belowground pools. Because of crop and green fodder, the aboveground biomass was removed completely, which reduced plant inputs into the soil (Zhou et al. 2007) and reduced soil macro-aggregate formation (Wiesmeier et al. 2019). Particularly, the annual cotton was distinguished from other perennial plants, the long-term tillage led to soil erosion, reduced the stabilization of SOM due to deteriorated aggregation, and accelerated the subsequent mineralization (Balesdent et al. 2000, Hamza and Anderson 2005). Therefore, the optimal use of management practices for reclamation (ECO and LAL) should be implemented to increase SOC and improve soil fertility.

High-resolution land use data (i.e., area, species, and duration) in the YRD area was currently not available, largely due to the frequent land use change in this area. Nevertheless, results of our study shed light on the potential change of carbon stocks at landscape and regional scales in the YRD area. Up to 93% of the land in the YRD belongs to the administration area of Dongying City (Wang et al. 2006). The statistical data of land use in the Dongying City showed that this area experienced substantial land use change from 2000 to 2010 (Zhang and Zhao 2015), represented by the conversion of saline–alkali land to cultivated land (Appendix S1: Table S3). In the study area, the native shrubs such as the Chinese tamarisk (*T. chinensis*) typically occupied the saline–alkali land, native herbs and reeds grew on the natural grassland, and the cultivated land may be occupied by either artificial leguminous herbage or economic crops. With these approximations, we estimated that up to

184.96 × 10^4 t C may have been released with the conversion of saline–alkali land to cultivated land in the YRD area from 2000 to 2010, and this release of carbon primarily came from the SOC pool (Table 3). The conversion of saline–alkali land to natural grassland, and natural grassland to cultivated land was accompanied by a moderate decrease in total carbon stocks, primarily due to the magnitude of these land use conversions in the YRD area (Table 3). There have always been reports about soil carbon release caused by land use conversion. Fu et al. (2010) reported that the SOC pool of 0–1 m depth decreased by 7 Pg due to cultivation of natural soils according to the database of China's second national soil survey (Wu et al. 2003, Fu et al. 2010). Smith (2008) reported that soils had lost more than 40 Pg C through cultivation and other disturbance during the 1990s globally (Smith 2008). Therefore, less impact of land management practices should always be a great concern for both global climate change and regional productivity.

Although there are some differences about the effect of land use conversion on SOC pool due to different ecosystems and regions or spatial heterogeneity, results of our study strongly suggest that land reclamation in the YRD area is likely to release soil carbon. Therefore, protecting native vegetation ecosystems from reclamation is the best measure in terms of carbon sequestration. In view of the increasing number of reclaimed lands, combined with our survey data of carbon pool, planting perennial forage can increase carbon stocks, and the increased carbon is primarily allocated to plant biomass. If the reclaimed land be used to plant crops, cautions such as conservation tillage should be applied in order to reduce carbon release in the context of mitigating global climate.

Conclusions

The study provided a comprehensive and quantitative assessment of ecosystem-scale carbon stocks and allocation among different land uses in the YRD, China. The results indicated that carbon stocks had great variation and different allocation ratios across the primary land uses in the study area. Natural vegetation ecosystems of RAE and CTA had the largest soil carbon stocks and the strong proportion of carbon allocation to soil pools. This argued strongly that the YRD area was likely an important carbon sink prior to the large-scale reclamation in the 1950s. This inference was further confirmed by an estimation of regional carbon stocks as a result of land use changes in the YRD area, which was up to 184.96 × 10^4 t C that may have been released with the conversion of saline–alkali land to cultivated land in the YRD area from 2000 to 2010. Our results shed light on the potential change of carbon stocks at landscape and regional scales, which may be a base, regional guidance of rational land use in the YRD area. In terms of extensive and rapid development of industry and agriculture in the YRD area, we suggest that the impact of diversity in land uses on ecological safety should be viewed as essential concern of the long-term economic development and wetland ecosystem stability.

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