Dynamic variation characterization of soil organic and inorganic carbon of saline-alkali paddy fields and the influence factors

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Abstract. The paper aims at revealing the dynamic variation characterization of soil carbon content and the influence factors. The experiments were conducted in the Qianguo irrigation area located in western Jilin Province, and the soil samples were collected from saline-alkali bare land and saline-alkali paddy fields of different reclamation years. The dynamic variations of soil organic carbon (SOC) and soil inorganic carbon (SIC) during various growing stages were analysed. The effects of soil enzymes and chemical properties on SOC and SIC were illustrated. The results showed that SOC content initially decreased at the seedling and tillering stages, then increased at the heading stage, and finally decreased at the grain filling stage. However, SIC content initially increased at the seedling and tillering stages, then decreased at the heading stage, and finally increased at the grain filling stage. Rice growth had the effect of carbon sink. Both the reclamation of paddy field and the growing stages had significant effects on SOC and SIC contents. SOC was significantly positively correlated with the available nitrogen, invertase and catalase, and was negatively correlated with SIC, pH and conductivity, while SIC presented to be totally opposite. The conductivity and catalase had significant effects on SOC contents, while the available nitrogen and conductivity had significant effects on SIC.

1. Introduction
Soil carbon pool is the largest carbon pool on the earth surface, and its change has profound implications for atmospheric CO₂ content [1]. The soil organic carbon (SOC) and the soil inorganic carbon (SIC) are both important components of the soil carbon pool. However, there are only a few studies of SIC now [2]. SIC is a common form of soil carbon pool in the arid and semiarid regions that cover one-third of the planet [3]. The storages of SIC pool are approximately 2-10 times more than those of SOC [4], and the accumulation rates are also higher than those of SOC [5]. Therefore, the effect of SIC on soil carbon pool cannot be ignored [6, 7]. The soil carbon pool of paddy fields is an active component of the global carbon pool. Large amounts of carbonates and bicarbonates in saline-alkali paddy soil has the special contribution to the change of carbon pool. However, there are few studies on soil carbon change in saline-alkali paddy fields, especially for inorganic carbon.
The influence factors of carbon changes are hot topics of carbon cycle, but the influence factors in saline-alkali environment are still not clear, especially those of SIC. Soil pH, conductivity and available nitrogen are important chemical factors for carbon changes in saline-alkali soil [8]. Soil enzymes control the intensity and direction of biochemical reactions in soil and are important indicators of soil microbial activities. Hence, the effects of soil chemical properties and soil enzymes on SOC and SIC are important problems of soil carbon cycle in saline-alkali paddy fields.

The experiments were conducted in Qianguo irrigation area located in western Jilin Province. The characteristics of SOC and SIC during different growing stages of rice were analyzed, and the main influence factors of carbon changes in saline-alkali paddy fields were revealed. The results have significance for evaluating the carbon storage and revealing the mechanism of carbon cycle under saline-alkali stress.

2. Materials and methods
Western Jilin Province is an important agriculture and livestock production base of China and is considered one of the world’s largest soda saline-alkali areas. This area with a typical semiarid and semi-humid monsoon climate belongs to the Northeast China Transect of global climate change research and is a sensitive area for climate change.

Paddy fields reclaimed for 5, 15, 25, 35 and 55 years and uncultivated saline-alkali bare land were selected as sampling plots in Qianguo irrigation area. Soil samples were collected at no planting, seedling, tillering, heading and grain filling stages. 12 sampling points were randomly selected from each plot by snake method, and the topsoil samples from 0 to 30cm were collected. Every four samples in each plot were evenly mixed into one sample by four division method and taken back to the laboratory for testing.

Organic carbon and inorganic carbon were determined by total organic carbon analyzer. pH was determined by potentiometric method. Conductivity was determined by conductance method to characterize the salt content. The available nitrogen was measured by alkaline hydrolysis diffusion method. Invertase activity was measured by 3-5 dinitrosalicylic acid colorimetry. Catalase activity was determined by potassium permanganate titration. Three repetitions were set for each sample.

3. Results and discussion
SOC content initially decreased at the seedling and tillering stages, then increased at the heading stage, and finally decreased at the grain filling stage (Figure 1). SOC content of paddy fields reclaimed for 5, 15, 25, 35 and 55 years increased by 0.50 g/kg on average after a growing season. The results showed that rice growth could promote the accumulation of SOC, which improved soil quality and contributed to soil carbon sequestration.

SIC content initially increased at the seedling and tillering stages, then decreased at the heading stage, and finally increased at the grain filling stage (Figure 2). SIC content of paddy fields of five reclamation years increased by 0.11 g/kg on average after a growing season. It indicated that rice growth could promote SIC accumulation, which contributed to soil carbon sequestration.

Variance analysis showed that the reclamation years and the growing stages had significant effects on carbon changes of saline-alkali paddy fields (P < 0.05). Thus, both the reclamation of paddy field and the growing stages were the main factors affecting SOC and SIC contents.
Soil enzymes and chemical properties were significantly correlated with SOC and SIC (Table 1). SOC was significantly positively correlated with the available nitrogen, invertase and catalase (P<0.01), and is negatively correlated with SIC, pH and conductivity (P<0.01). SIC is significantly positively correlated with pH and conductivity (P<0.01), and is negatively correlated with the available nitrogen, invertase and catalase (P<0.01).
Table 1. Correlation coefficients of SOC, SIC, chemical properties and soil enzymes.

|        | SOC   | SIC   | pH    | Conductivity | Available nitrogen | Invertase | Catalase |
|--------|-------|-------|-------|--------------|------------------|-----------|----------|
| SOC    | 1     | -0.941** | -0.823** | -0.934** | 0.887*** | 0.766** | 0.915** |
| SIC    |       | 1     | 0.659** | 0.916** | -0.977** | -0.593** | -0.812** |
| pH     |       |       | 1     | 0.851** | -0.581** | -0.700** | -0.721** |
| Conductivity |       |       |       | 1       | -0.895** | -0.581** | -0.761** |
| Available nitrogen |       |       |       |          | 1         | 0.496** | 0.753** |
| Invertase |       |       |       |          |           | 1         | 0.877** |
| Catalase |       |       |       |          |           |           | 1        |

Note. **significant at 0.01 level, * significant at 0.05 level.

Multivariate linear analysis was carried out with SOC (Y_1) as dependent variable, pH (X_1), conductivity (X_2), available nitrogen (X_3), invertase (X_4) and catalase (X_5) as independent variables (Table 2).

The multiple regression analysis showed the catalase had the greatest impact on SOC, followed by conductivity, available nitrogen, pH and invertase. The optimal regression equation obtained by stepwise regression analysis was Y_1=10.501-9.962X_2+61.388X_5.

Table 2. Regression model of SOC

| Model | R    | F     | P    | Constant and variables | Standard coefficient | Standard regression coefficient | P   |
|-------|------|-------|------|------------------------|----------------------|--------------------------------|-----|
|       |      |       |      | constant               | 26.866               | 0.137                          |     |
| 1     | 0.988| 201.919| <0.001| pH                     | -2.272               | -0.121                         | 0.337|
|       |      |       |      | conductivity           | -5.184               | -0.295                         | 0.145|
|       |      |       |      | available nitrogen     | 26.123               | 0.271                          | 0.067|
|       |      |       |      | invertase              | 0.218                | 0.112                          | 0.176|
|       |      |       |      | catalase                | 38.210               | 0.301                          | 0.007|
|       |      |       |      | constant               | 27.431               | <0.001                         |     |
|       |      |       |      | conductivity           | -16.430              | -0.934                         | <0.001|
| 2     | 0.934| 192.807| <0.001| constant               | 10.501               | <0.001                         |     |
|       |      |       |      | conductivity           | -9.962               | -0.567                         | <0.001|
|       |      |       |      | catalase                | 61.388               | 0.483                          | <0.001|

Note. SOC is the dependent variable. Model 1 is the multiple regression analysis, and Model 2 and Model 3 are the stepwise regression analysis.

Multivariate linear analysis was carried out with SIC (Y_2) as dependent variable, pH (X_1), conductivity (X_2), available nitrogen (X_3), invertase (X_4) and catalase (X_5) as independent variables (Table 3).

The multiple regression analysis showed the available nitrogen had the greatest impact on SIC, followed by conductivity, invertase, catalase and pH. The optimal regression equation obtained by stepwise regression analysis was Y_2=5.818-15.601X_3-0.050X_4.
Table 3. Regression model of SIC

| Model | R     | F      | P        | Constant and variables | Standard coefficient | Standard regression coefficient | P  |
|-------|-------|--------|----------|------------------------|----------------------|-------------------------------|----|
| 1     | 0.987 | 179.353| <0.001   | constant                | 5.925                | -0.023                        | 0.863|
|       |       |        |          | pH                     | -0.076               | 0.159                         | 0.451|
|       |       |        |          | conductivity           | 0.500                | -0.768                        | 0.000|
|       |       |        |          | available nitrogen     | -13.218              | 0.042                         | 0.703|
|       |       |        |          | invertase              | -0.035               | -0.100                        | 0.255|
|       |       |        |          | catalase               | -0.944               | -0.042                        | 0.001|
| 2     | 0.977 | 599.507| <0.001   | constant                | 5.583                | -0.977                        | <0.001|
|       |       |        |          | available nitrogen     | -16.831              | -0.906                        | <0.001|
| 3     | 0.985 | 452.909| <0.001   | constant                | 5.818                | -0.144                        | 0.001|
|       |       |        |          | available nitrogen     | -15.601              | -0.906                        | <0.001|
|       |       |        |          | invertase              | -0.050               | -0.144                        | 0.001|

Note. SIC is the dependent variable. Model 1 is the multiple regression analysis, and Model 2 and Model 3 are the stepwise regression analysis.

4. Conclusion
SOC and SIC of saline-alkali paddy fields showed obvious variation characteristics during different growing stages of rice. Rice growth had the effect of carbon sink. Both the reclamation of paddy field and the growing stages had significant effects on SOC and SIC contents. SOC was significantly positively correlated with the available nitrogen, invertase and catalase, and was negatively correlated with SIC, pH and conductivity, while SIC presented to be totally opposite. The catalase had the greatest impact on SOC, followed by conductivity, available nitrogen, pH and invertase. However, the available nitrogen had the greatest impact on SIC, followed by conductivity, invertase, catalase and pH.

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