

Article

Vertical Distribution and Controlling Factors of Soil Inorganic Carbon in Poplar Plantations of Coastal Eastern China

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Abstract: Afforestation is a strategy to protect croplands and to sequester carbon in coastal areas. In addition, inorganic carbon is a considerable constituent of the coastal soil carbon pool. However, the vertical distribution and controlling factors of soil inorganic carbon (SIC) in plantations of coastal areas have been rarely studied. We analyzed the SIC content as well as physiochemical properties along soil profiles (0–100 cm) in young (YP) and mature (MP) poplar plantations in coastal eastern China. The soil profile was divided into six layers (0–10, 11–20, 21–40, 41–60, 61–80 and 81–100 cm) and a total of 36 soil samples were formed. The SIC content first increased from 0–10 cm (0.74%) to 11–20 cm (0.92%) and then fluctuated in the YP. In contrast, the SIC content increased with increasing soil depth until 40 cm and then leveled off, and the minimum and maximum appeared at 0–10 cm (0.54%) and 81–100 cm (0.98%) respectively in the MP. The soil inorganic carbon density was 12.05 and 12.93 kg m^{−2} within 0–100 cm in the YP and MP, respectively. Contrary to SIC, soil organic carbon (SOC) first decreased then levelled off within the soil profiles. Compared with the YP, the SIC content decreased 27.8% at 0–10 cm but increased 13.2% at 21–40 cm, meanwhile the SOC content in MP decreased 70.6% and 46.7% at 21–40 cm and 61–80 cm, respectively. The water-soluble Ca²⁺ and Mg²⁺ gradually decreased and increased, respectively within the soil profiles. The soil water-soluble Ca²⁺ increased 18.3% within 41–100 cm; however, the soil water-soluble Mg²⁺ decreased 32.7% within 21–100 cm in the MP when compared to the YP. Correlation analysis showed that SIC was negatively correlated with SOC, but positively correlated with soil pH and water-soluble Mg²⁺. Furthermore, structural equation modeling (SEM) indicated that SOC was the most important factor influencing the SIC content in the studied poplar plantations, indicating SOC sequestration promoted the dissolution of SIC. Therefore, our study highlights the trade-off between SIC and SOC in poplar plantations of coastal Eastern China.



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Keywords: coastal soil; poplar plantation; soil inorganic carbon; soil organic carbon

1. Introduction

Soil carbon consists of organic carbon and inorganic carbon. Soil inorganic carbon (SIC) mainly refers to the soil mineral carbonates produced by the weathering of soil parent material, which includes lithogenic inorganic carbon and pedogenic inorganic carbon [1,2]. Globally, the amount of total soil carbon pool was approximately 2157–2293 Pg C in the upper 100 cm, while SIC accounted for about one third of total soil carbon [3].

The soils in arid, semi-arid, semi-humid, and coastal areas usually contain a relatively high content of inorganic carbon. Previous studies have reported that the variation of SIC content with soil depth in arid and semi-arid regions, and it can be categorized into three types: increase [4–6], increase followed by decrease [7–9], and no difference in the vertical direction [10]. Recently, Yang et al. [11] reported the SIC first increased then decreased with the increase of soil depth in *Spartina alterniflora* (Loisel.) wetlands in the east-central China coast, however, the opposite vertical distribution was reported by Zhang et al. [12], who

studied the same ecosystem type in the Yellow River Estuary, China. Therefore, the vertical distribution of SIC is complicated and varied with different soils and areas.

It was suggested that the intrinsic soil properties, rainfall runoff, and different land management practices impacted soil carbonate in semi-arid regions [13]. Soil moisture could affect the distribution of SIC in soil profiles through leaching and infiltration [14,15]. The soil bulk density affects soil porosity, and higher bulk density is generally accompanied by lower soil porosity, which could increase the partial pressure of carbon dioxide ($p\text{CO}_2$) and promote the formation of soil carbonate [16]. SIC is mainly composed of carbonate (such as CaCO_3 and MgCO_3). High soil pH was more conducive to SIC preservation because it could consume H^+ , which could dissolve and decrease SIC [17,18]. Land-use change also affected SIC storage. Compared with the cropland, forest has a higher amount of aboveground litter, fine root biomass and soil organic carbon (SOC) stocks, which could promote the dissolution and leaching of SIC, and thus affected the vertical distribution of SIC [19]. However, the controlling factor on SIC content are still controversial [17,20–22]. For example, Tong et al. [23] reported that sand content played an important role in predicting SIC in erosional and depositional sites in Chinese Loess Plateau. Similarly, a recent work showed that the relative content of silt, clay, and sand was the most vital factor affecting the accumulation of SIC in tidal flats [21]. In contrast, Zhang et al. [24] found CaO was the predominant factor controlling SIC content in reclaimed coastal tidal flats. Therefore, it is necessary to study the key factors affecting the accumulation of SIC in different soils.

Afforestation in coastal areas is one of the important land use types in coastal areas [25]. Poplar is characterized by fast growth, high yield and easy renewal. The plantation area and timber volume of poplar in Jiangsu Province ranked first in China [26]. However, the vertical distribution of SIC content and the key factors affecting SIC content in poplar plantations in this area have not been reported. Dongtai Plantation Farm, located at north of Jiangsu Province, is the largest coastal protective plantation. In this study, we measured SIC and various soil physiochemical properties, such as pH, EC, SOC, soil water-soluble Ca^{2+} and Mg^{2+} along 0–100 cm soil profiles in two poplar plantations of different ages. Therefore, this study aimed to (1) analyze the vertical distribution of SIC; (2) determine the controlling factors influencing SIC content in the poplar plantations. This study will increase the knowledge of SIC in poplar plantations in coastal areas.

2. Materials and Methods

2.1. Site Description

The soils were sampled in Dongtai Plantation Farm, Yancheng City, Jiangsu Province ($120^\circ 49' \text{ E}$, $32^\circ 52' \text{ N}$). This area has a marine monsoon climate. The annual average temperature, rainfall and relative humidity is 14.6°C , 1050 mm and 88.3%, respectively, and the annual average frost-free period and sunlight duration is 220 d and 2200 h, respectively. The soil parent material is marine alluvial deposits, and the soil type belongs to desalting meadow soil with the texture of sandy loam.

Dongtai Plantation Farm has a total area of 2867 ha with the forest area of 2187 ha. The forest coverage and total timber volume of Dongtai Plantation Farm is about 85% and 50,000 m^3 , respectively. The main tree species are *Populus deltoids* L. cv. I-72, *Populus deltoids* L. cv. I-69, *Populus deltoids* L. cv. I-35, *Metasequoia glyptostroboides* Hu & W. C. Cheng et al. The herbaceous species include *Apocynum venetum* L., *Humulus scandens* (Lour.) Merr., *Rosa multiflora* Thunb., and ferns.

2.2. Soil Sampling

The poplar plantations selected in this study were planted with *Populus deltoids* L. cv. I-35 in 2012 and *Populus deltoids* L. cv. I-69 in 1993, respectively. Therefore, the forest age was 7 and 26 years (a) by 2019 and they were young (YP) and mature poplar (MP) plantations, respectively (Figure 1). The total plantation area is 5.7 ha for YP and 9.3 ha for MP, and the stand characteristics were shown in Table 1.

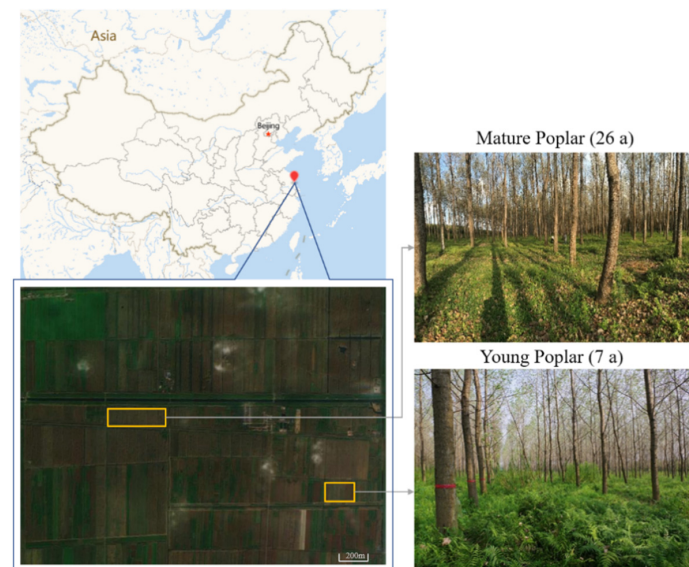


Figure 1. Study location in the eastern coast of China, the satellite image was obtained from 1:4 million China soil type map.

Table 1. The stand characteristics in the young (YP) and mature poplar (MP) plantations.

Age of Plantation (a)	Stand Density (Plants ha ⁻¹)	Row Spacing (m × m)	Mean Height (m)	Mean DBH * (cm)	Canopy Density (%)
7	417	4 × 6	19.6	18.9	85
26	108	6 × 8	29.8	35.6	60

*: DBH means diameter at breast height.

Three replicate plots (20 m × 20 m) were established in each site. Five soil profiles of 0–100 cm were excavated along a “S” curve in each plot. Each soil profile was divided into six layers (i.e., 0–10, 11–20, 21–40, 41–60, 61–80 and 81–100 cm). Five soil samples of the same layer in each plot were mixed to produce one composite sample. In total, 36 composite soil samples were formed. Visible roots and other debris were removed from soil samples, and then the moist soil samples were taken to the laboratory.

2.3. Soil Physicochemical Analysis

The ring knife (100 cm³) samples from the field were brought to the laboratory, and oven dried at 105 °C until constant weight to measure the soil bulk density (BD). Soil pH and electrical conductivity (EC) were measured in the soil:water (m/m 1:5) mixture using a compound pH electrode and a conductivity electrode, respectively. To determine the content of soil water-soluble Ca²⁺ and Mg²⁺, the soil was first extracted with the distilled water (m/m 1:5), and then measured by atomic absorption spectrophotometer (AA900T, Perkin Elmer, Waltham, MA, USA). Soil total carbon (TC) was determined by elemental analyzer (PE2400, Pekin Elmer, Waltham, MA, USA). SOC was measured by the K₂Cr₂O₇–H₂SO₄ oxidation method. SIC was calculated as the difference between TC and SOC.

2.4. Calculations

The calculation of SICD (C_i , kg m⁻²) of soil layer i was as follows:

$$C_i = SIC_i \times D_i \times H_i / 10 \quad (1)$$

where SIC_i is the SIC content of soil layer i (%); D_i is the bulk density of soil layer i (g cm⁻³); H_i is the thickness of soil layer i (cm); and 10 is the unit conversion factor.

2.5. Statistical Analysis

One-way analysis of variance (ANOVA) was conducted to test the significance of differences of SIC content and other soil properties among different soil layers within a poplar plantation. Further, the least significant difference (LSD) was used for post-hoc multiple comparisons. An independent sample *t*-test was employed to examine the differences in SIC content and other soil properties between the two poplar plantations. The relationship between SIC content and soil physicochemical properties was analyzed by the Pearson correlation analysis. The statistical significance was set at $p < 0.05$. Structural equation modeling (SEM) was used to investigate direct and indirect effects of soil physicochemical properties on SIC. The model was tested with Chi-squared tests (χ^2 tests), the comparative fit index (CFI), the goodness-of-fit statistic (GFI) and the root mean square error of approximation (RMSEA). The acceptance criteria of SEM model was as follows: $\chi^2 > 0.05$, GFI > 0.90 , CFI > 0.95 and RMSEA < 0.05 [27]. SEM model was performed by Lavaan package in R software (v 4.1.1). All other statistical analyses were performed with SPSS 22.0 for Windows (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Soil Water Content and Soil Bulk Density

Soil water content gradually increased with the increase of soil depth in the YP, and the maximum (29.0%) at 81–100 cm was nearly two times of the minimum at 0–10 cm (15.6%) (Figure 2). However, soil water content was rather constant along soil profiles in the MP, and the maximum (29.6%) appeared at 81–100 cm (Figure 2). Compared with the YP, the soil water content was obviously higher within 0–60 cm in the MP (Figure 2). The averaged soil water content across 0–100 cm in the MP (27.9%) was higher than that in the YP (23.79%). There was no significant difference in soil bulk density between YP and MP, but soil BD of MP was 7.2% higher compared to YP within 0–60 cm, instead, the soil BD of YP was slightly higher than MP within 61–100 cm. The averaged soil BD across the profiles was 1.42 and 1.37 g cm^{−3} in the MP and YP, respectively.

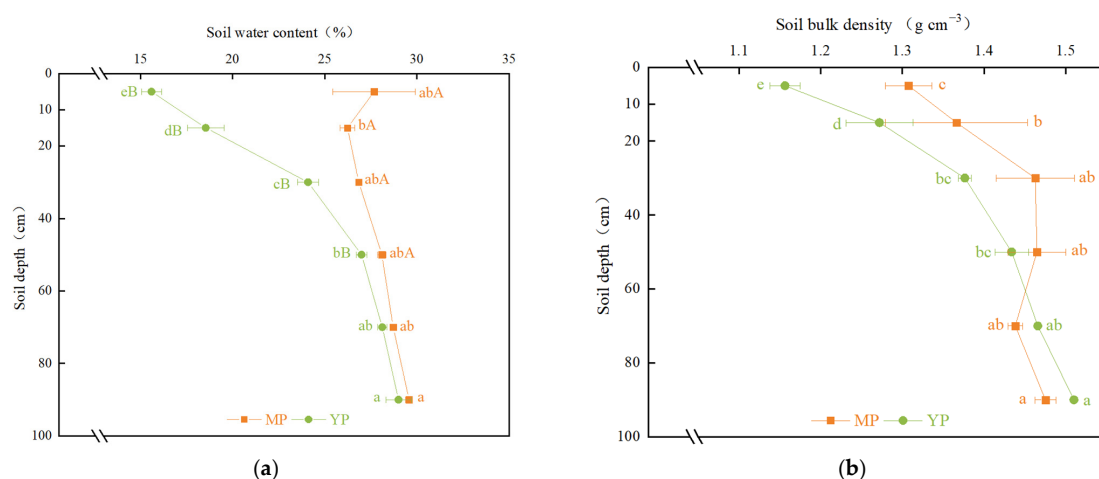


Figure 2. Changes of soil water content (a) and soil bulk density (b) along 0–100 cm soil profiles in the mature (MP) and young poplar (YP) plantations. Different lowercase letters denote significant differences among different depths within the same plantation; while different uppercase letters denote significant differences between different plantations within the same soil depth ($p < 0.05$).

3.2. Soil Inorganic Carbon

The SIC content increased with the increase of soil depth until 40 cm and then leveled off, and the maximum appeared at 81–100 cm (0.98%) in the MP (Figure 3a). The SIC content first increased from 0–10 to 11–20 cm and then displayed a fluctuating trend along the soil profiles, and the maximum appeared at 40–60 cm (0.97%) in the YP (Figure 3a). The minimum SIC both appeared at 0–10 cm, which was 0.54% and 0.74% in the MP and

YP, respectively (Figure 3a). When compared to the YP, the SIC content decreased 27.8% at 0–10 cm while it increased 13.2% at 21–40 cm in the MP (Figure 3a). When averaged across soil profiles, there was no difference in SIC content in YP and MP, which was 0.88% and 0.86%, respectively. The variation of SICD with soil depth was similar with that of SIC content (Figure 3b). The SICD within 0–100 cm in the MP (12.93 kg m^{-2}) was higher than that in the YP (12.05 kg m^{-2}) (Figure 3b), primarily due to the higher soil bulk density in the MP ($1.42 \text{ vs. } 1.37 \text{ g cm}^{-3}$).

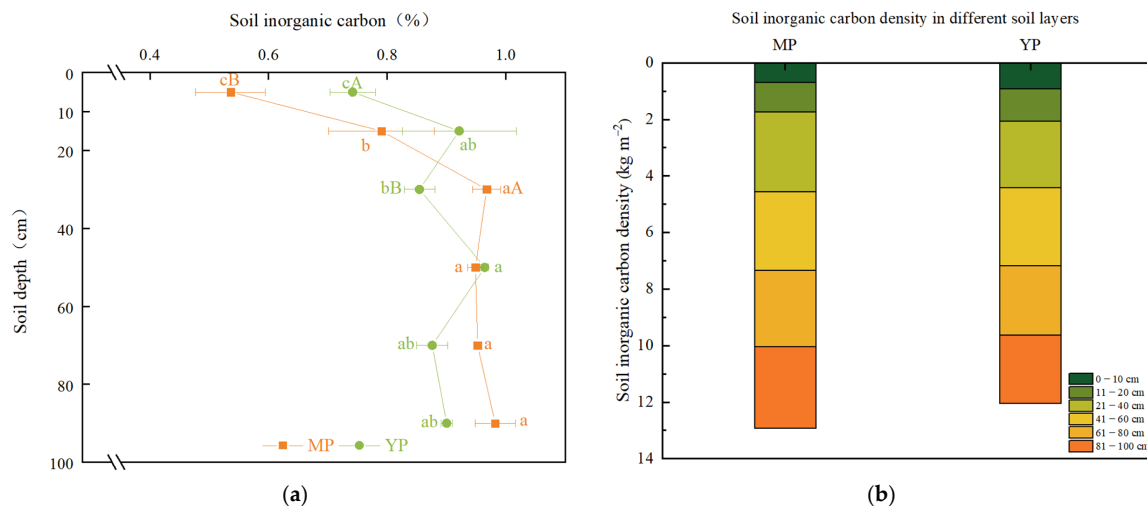


Figure 3. Changes of soil inorganic carbon (a) and soil inorganic carbon density (b) along 0–100 cm soil profiles in the mature (MP) and young poplar (YP) plantations. Different lowercase letters denote significant differences among different depths within the same plantation; while different uppercase letters denote significant differences between different plantations within the same soil depth ($p < 0.05$).

3.3. Soil Organic Carbon

Contrary to SIC, the SOC content first decreased then levelled off along soil profiles in both plantations (Figure 4). Specifically, the SOC decreased 83.6% from 0.73% at 0–10 cm to 0.12% at 41–60 cm in the YP, while it decreased 87.5% from 0.80% at 0–10 cm to 0.10% at 21–40 cm in the MP (Figure 4). Compared to the YP, the SOC content at 21–40 cm and 61–80 cm decreased 70.6% and 46.7%, respectively in the MP (Figure 4). When averaged across soil profiles, the SOC content was 0.33% and 0.25% in the YP and MP, respectively.

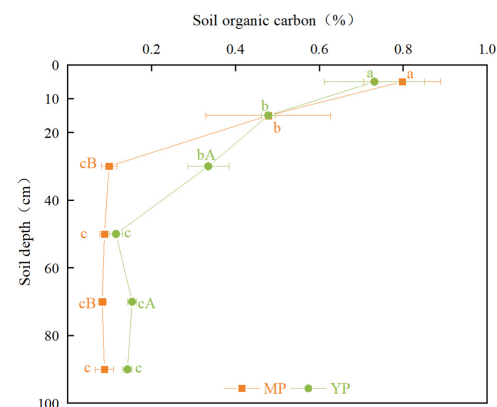


Figure 4. Changes of soil organic carbon along 0–100 cm soil profiles in the mature (MP) and young poplar (YP) plantations. Different lowercase letters denote significant differences among different depths within the same plantation; while different uppercase letters denote significant differences between different plantations within the same soil depth ($p < 0.05$).

3.4. Soil pH and Electrical Conductivity

The soil pH showed an increasing trend with the increase of soil depth in both plantations (Figure 5a). The soil pH increased from 8.03 to 9.16 and from 8.01 to 9.05 in the YP and MP, respectively (Figure 5a). However, the soil EC was rather constant with the increase of soil depth (Figure 5b). The averaged soil EC across soil profiles was 57.1 and 58.7 ms cm^{-1} in YP and MP, respectively.

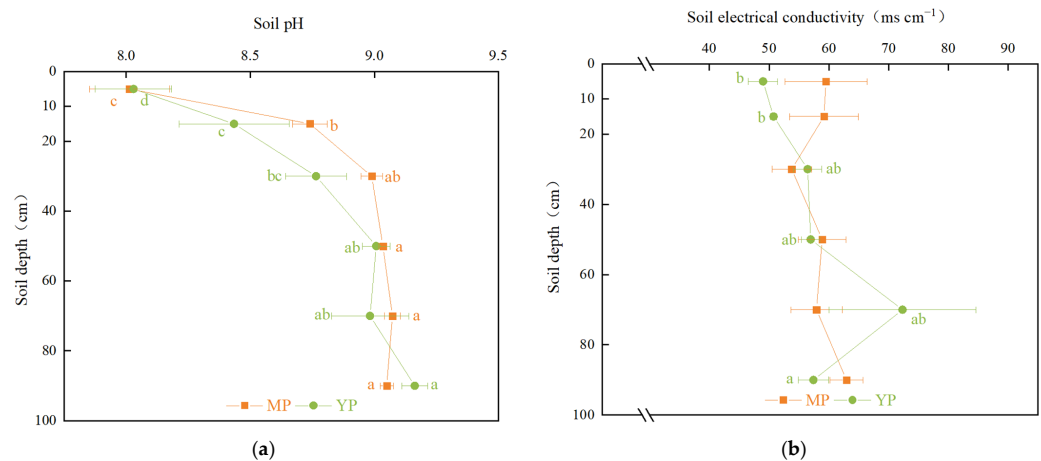


Figure 5. Changes of soil pH (a) and soil electrical conductivity (b) along 0–100 cm soil profiles in the mature (MP) and young poplar (YP) plantations. Different lowercase letters denote significant differences among different depths within the same plantation; while different uppercase letters denote significant differences between different plantations within the same soil depth ($p < 0.05$).

3.5. Soil Water-Soluble Ca^{2+} and Mg^{2+}

The soil water-soluble Ca^{2+} content generally decreased with the increase of soil depth in both plantations (Figure 6a). The averaged soil water-soluble Ca^{2+} across 0–100 cm was 62.0 and 66.5 mg kg^{-1} in the YP and MP, respectively. The vertical distribution of soil water-soluble Mg^{2+} was exactly contrary to that of the water-soluble Ca^{2+} in both plantations (Figure 6b). Compared to the YP, the soil water-soluble Ca^{2+} increased 18.3% at 41–100 cm (Figure 6a); however, the soil water-soluble Mg^{2+} decreased 32.7% at 21–100 cm in the MP (Figure 6b). The averaged soil water-soluble Mg^{2+} across 0–100 cm was 9.27 and 6.87 mg kg^{-1} in the YP and MP, respectively.

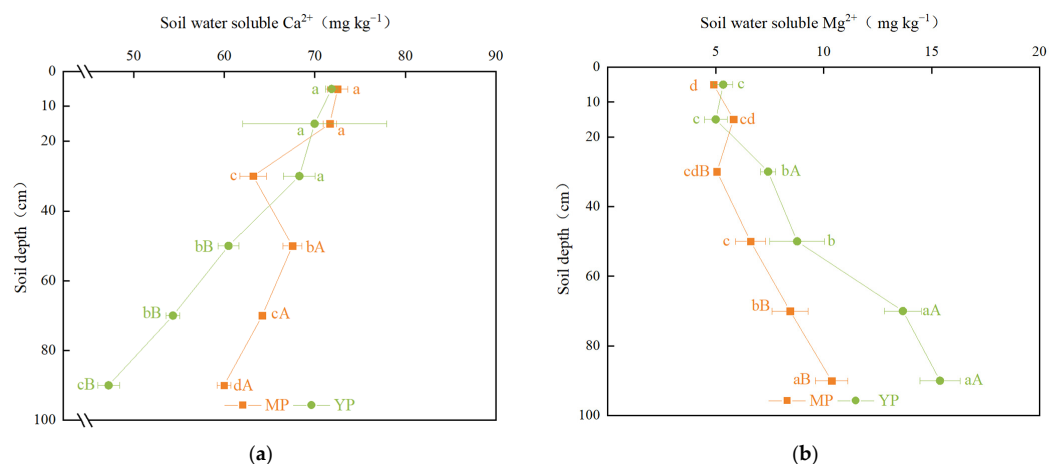


Figure 6. Changes of soil water-soluble Ca^{2+} (a) and Mg^{2+} (b) along 0–100 cm soil profiles in the mature (MP) and young poplar (YP) plantations. Different lowercase letters denote significant differences among different depths within the same plantation; while different uppercase letters denote significant differences between different plantations within the same soil depth ($p < 0.05$).

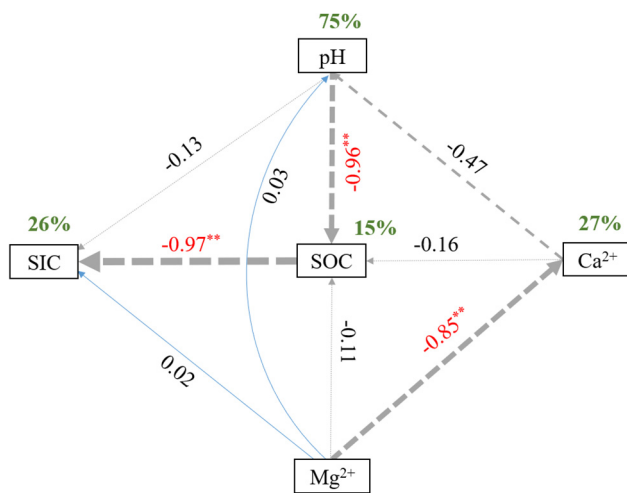
3.6. Factors Influencing Soil Inorganic Carbon Content

Correlation analysis showed that SIC was negatively correlated with SOC and positively correlated with soil pH and water-soluble Mg^{2+} (Table 2). SEM showed that SOC was the controlling factor of SIC (Figure 7a). Soil water-soluble Ca^{2+} could indirectly influence SIC, i.e., soil water-soluble $Ca^{2+} \rightarrow$ soil pH / SOC $\rightarrow$ SIC (Figure 7a). The total effect of SOC on SIC was the highest (-0.97), followed by soil pH (0.79), water-soluble Mg^{2+} (0.53) and water-soluble Ca^{2+} (-0.60) (Figure 7b).

Table 2. Correlation analysis between soil inorganic carbon content and physiochemical properties ($n = 36$).

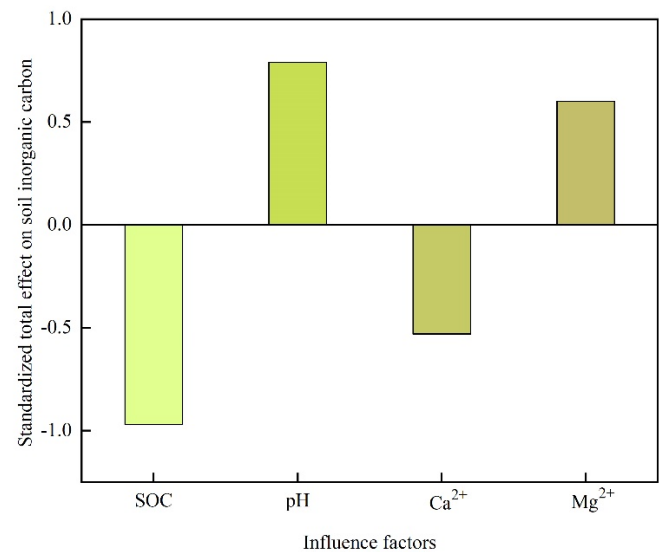
Indicators	SIC	SOC	pH	EC	Water-Soluble Ca^{2+}	Water-Soluble Mg^{2+}	Soil Water Content
SIC	1						
SOC	-0.860^{**}	1					
pH	0.772^{**}	-0.920^{**}	1				
EC	-0.122	-0.126	0.207	1			
Water-soluble Ca^{2+}	-0.303	0.404^{*}	-0.498^{**}	-0.128	1		
Water-soluble Mg^{2+}	0.334^{*}	-0.382^{*}	0.433^{**}	0.073	-0.852^{**}	1	
Soil water content	0.205	0.574^{**}	0.593^{**}	0.457^{**}	-0.368^{*}	0.318	1

Note: $^{*} p < 0.05$, $^{**} p < 0.01$.



$p = 0.312$, GFI = 0.995, CFI = 1.000, RMSEA = 0.026

(a)



(b)

Figure 7. SEM model analysis of SIC and soil physicochemical properties in poplar plantations (a) and the standardized total effects (b). SEM model analysis (a) explains the direct or indirect effects of soil physicochemical properties on SIC content; the SEM model was used to calculate the standardized total effect (direct effect + indirect effect) (b). Gray dashed arrows are negative correlations and blue solid arrows are positive correlations; the numbers next to the lines represent the standardized path coefficients and the arrow widths are proportional to the magnitude of the path coefficients. Red numbers represent significant differences ($^{**} p < 0.01$).

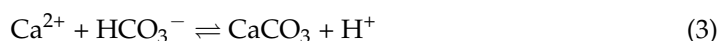
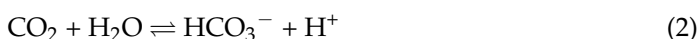
4. Discussion

4.1. Vertical Distribution of Soil Inorganic Carbon Content and Density

In our study, the SIC content first increased then levelled off with the increase of soil depth, ranging from 0.54% to 0.98% in the studied plantations (Figure 3a). The vertical distribution of SIC within 0–100 cm was consistent with Wang et al. [28] who studied the saline soil in the southern Gurbantongute desert. Gao et al. [29] reported that SIC content was 2.64–5.24 g kg⁻¹ in poplar plantations aged 8–30 a in Northwest China. Lu et al. [30]

found that the SIC content ranged from 10.25 to 12.38 g kg⁻¹ in the cropland under wheat-maize rotation in Loess Plateau. Recently, Yang et al. [21] reported that the SIC and SOC content were in the range of 6.43–13.93 g kg⁻¹ and 1.62–14.43 g kg⁻¹ in coastal wetlands of Northern Jiangsu. The SOC content first decreased then levelled off along 0–100 cm soil profiles, and it ranged from 0.08–0.80% (Figure 4). Wang et al. [31] reported that the SOC content were significantly decreased under 20 cm which was almost less than 1 g kg⁻¹ (20–100 cm) in two of the sample plots in Laizhou Bay. Therefore, the SIC and SOC contents in our study fell within previously reported contents. Yang et al. [11] reported the SICD in the Jiangsu Yancheng Wetland National Reserve-Rare Birds was 12.52 kg m⁻² within 0–100 cm, which was similar in our study (12.05 and 12.93 kg m⁻², Figure 3b).

The accumulation of SIC in deep soils mainly involved the following two reactions. The CO₂ produced by SOC decomposition and root respiration would dissolve in soil moisture (Equation (2)). Furthermore, deep soils usually had high bulk density and low soil porosity, which could increase the pCO₂. The high pCO₂ would promote the formation of carbonates precipitation (Equation (3)) [32–34], thus the SIC content increased in deep soils.



4.2. The Effect of SOC on SIC

There was a negative relationship between SIC and SOC (Table 2). The finding was in line with previous findings [11,35,36]. Contrary to our finding, some studies found SOC and SIC were positively correlated [21,37,38]. This indicated that the processes involved in organic and inorganic carbon transformations were different in different soil environments. On one hand, the surface soil with high SOC content was rich in vegetation litter and soil microorganisms, which could decompose soil organic matter to produce more H⁺. The higher H⁺ would drive the (Equation (4)) to the right direction, leading to the dissolution of SIC [16]. On the other hand, high SOC content was usually accompanied by loose soil structure and high soil permeability, which could increase carbonate dissolution and leaching [13,23,39].



It is notable that SIC content in the YP was higher than that in the MP at the surface layers (0–10 and 11–20 cm), and it was the opposite at the deep layers (61–80 and 81–100 cm) (Figure 3a). Compared with YP, MP had a higher amount of SOC content in the topsoil (Figure 4). The organic acids produced during the process of SOC decomposition could promote the dissolution of SIC [18]. In addition, the soil water content in the MP was higher than that in the YP (Figure 2a). It was probable that the water-soluble SIC was more prone to leaching along soil profiles and resulted in the lower SIC at surface soils and the higher SIC at the deep soils in the MP.

4.3. The Effect of Soil pH on SIC

Our data indicated that the soil pH increased with the increase of soil depth (Figure 5a). Similar patterns were obtained in previous studies [11,13,29,40]. This might be due to that the soil soluble metal ions, such as Ca²⁺, Mg²⁺ were transferred from surface to the deep soil layers due to leaching [13,40]. Our results showed that pH was the second important factor influencing SIC content, and they were positively correlated (Figure 7b, Table 2). On one hand, the accumulation process of SIC led to enhancement of soil pH by consuming H⁺ [16]. On the other hand, greater alkalinity of the soil has higher buffer capacity for H⁺, which inhibited the dissolution of soil carbonate and allowed the accumulation of SIC in the deep soils [6,15,41].

4.4. The Effect of Soil Water-Soluble Ca^{2+} and Mg^{2+} on SIC

In our study, we found that the soil water-soluble Ca^{2+} and Mg^{2+} gradually decreased and increased with the increase of soil depth, respectively (Figure 6). Our result was consistent with a recent study in reed wetlands in the middle-lower Yellow River Delta, China by Guo et al. [42]. The rivers and groundwater could influence the movement of soil water-soluble Ca^{2+} and Mg^{2+} , thus affected their distribution in the soil profile [43]. Because the water solubility of Mg^{2+} was higher than that of Ca^{2+} , the soil water-soluble Mg^{2+} was easier to migrate from the top to the deep layers along the soil profiles. Therefore, soil water-soluble Mg^{2+} accumulated in the deep soil layers. We found the soil water-soluble Mg^{2+} decreased 32.7% at 21–100 cm in the MP compared to the YP (Figure 6b). Gao et al. [37] also found that the soil water-soluble Mg^{2+} in a 8 a poplar plantation was slightly higher than that in a 20 a poplar plantation. This was probably due to that some soil water-soluble Mg^{2+} was transformed into soil carbonate in the deep soils in the MP (Figure 3a).

Correlation analysis showed that SIC was positively correlated with soil water-soluble Mg^{2+} rather than soil water-soluble Ca^{2+} (Table 2). Our result was partially consistent with Shi et al. [6], who found neither the relationship between SIC stock and water-soluble Ca^{2+} nor that between SIC stock and water-soluble Mg^{2+} was significant in the wheat-maize croplands of the North China Plain. However, Guo et al. [41] found that SIC was positively correlated with both soil water-soluble Ca^{2+} and Mg^{2+} in the croplands of upper Yellow River Delta, China. Water-soluble Ca^{2+} and Mg^{2+} not only participated in the accumulation of carbonate, they would be absorbed and utilized by plants, or might be consumed in the leaching process [44]. Recently, Zhang et al. [12] found that soil Ca was the vital factor controlling SIC under different *Spartina alterniflora* invasion periods in a salt marsh ecosystem. Similarly, Zhang et al. [24] proposed that soil CaO was the factor with the highest importance in controlling SIC dynamic in reclaimed lands. Therefore, the different forms of Ca^{2+} , such as total, water-soluble and exchangeable Ca^{2+} might impose different effects on SIC content, which could be studied in the future.

5. Conclusions

The vertical distribution and controlling factor of SIC in coastal poplar plantations was first reported in this study. The SIC content first increased from 0–10 cm (0.74%) to 11–20 cm (0.92%) and then displayed a fluctuating trend along soil profiles in the YP. In contrast, the SIC content increased with the increase of soil depth until 40 cm and then leveled off, and the minimum and maximum appeared at 0–10 cm (0.54%) and 81–100 cm (0.98%), respectively, in the MP. SOC content first decreased then levelled off along the soil profiles. The soil water content, bulk density, pH, and water-soluble Mg^{2+} gradually increased while soil water-soluble Ca^{2+} gradually decreased along the soil profiles. Correlation analysis showed that SIC was negatively correlated with SOC, but positively correlated with soil pH and water-soluble Mg^{2+} . Both the correlation analysis and SEM showed that the SOC was the most important factor affecting the SIC content in the studied poplar plantations, and there was a trade-off between them. This was probably due to the CO_2 which was generated from SOC decomposition promoted the dissolution of SIC.

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