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Soil Aggregates Stability and Carbon Density Under Three Plantations on Loess Plateau, China

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Research

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Abstract

[Background] This paper aimed to research the influence of types of plantations on soil aggregate stability and carbon density. The soils of *Robinia pseudoacacia*, *Pinus tabulaeformis* and *M. pumila* plantations were selected as the research objects in the south of Loess Plateau. The mass percentages of soil water stable aggregates with different sizes were measured by fast wetting method, and then, the mean weight diameter (MWD) was calculated to asses soil aggregate stability. Soil organic carbon, inorganic carbon and bulk density were analyzed using traditional analysis methods. The roles played by soil organic and inorganic carbon in the formation of water stable aggregates were discussed.

[Results] The content of soil organic carbon and MWD was significantly higher in *P. tabuliformis* plantation compared with *R. pseudoacacia* and *M. pumila* plantations. Conversely, the content of soil calcium carbonate and total carbon density was the lowest in *P. tabuliformis* plantation. Soil organic carbon was the highest at the surface soils (0-10 cm), which was 2.21-3.96, 2.10-3.00 and 1.65-2.53 times compared with subsurface soils in *Robinia pseudoacacia*, *Pinus tabulaeformis* and *M. pumila* plantations respectively. While soil carbonate calcium and inorganic carbon density fluctuated with the increasing of soil layers. Aggregate organic carbon increased while carbonate calcium content decreased with the increasing of aggregate size respectively.

[Conclusion] We concluded that: (1) *P. tabuliformis* played a more important role in soil organic carbon sequestration compared with *R. pseudoacacia* and *M. pumila*; (2) there was a threshold value of carbonate calcium content, when it was lower or higher than this threshold, it had positive or negative correlation with MWD; (3) bigger water stable aggregates had higher soil organic matter and lower carbonate calcium.

Introduction

The area of plantation of trees in China has reached to 61.68 million hectares, coming the first in the world. In the study area, in order to accommodate degradation of soils, arid and cold climate, exotic species *Robinia pseudoacacia*, which is fast growing and aid N-fixation, has been introduced for a long time; and native species *Pinus tabulaeformis* has also been chosen as predominant reproducing tree species. Meanwhile, *Malus pumila* was also planted widely by local farmers in order to seek higher economic profits than others (such as *Triticum aestivum* and *Zea mays*). Each plant species provides a different quality and quantity of organic material into soils, causing changes of soil properties [9]. Chen et al. found the age-related fine root biomass [13] and C: N: P stoichiometry [12] were significantly different between *P. tabulaeformis* and *R. pseudoacacia* in the Loess Plateau. Bhattacharya et al. [23] showed tree species significantly changed soil properties through roots and litters. Zhang et al. [26] concluded that *P. tabulaeformis* plantation greatly increased plant residues and vegetation coverage, thereby improving soil micro-environment and ultimately improving physical-chemical properties and biological activities of soil. Mataix-Solera et al. [9] concluded that compared with other species, *Pinus halepensis* should be planted in afforestation projects in semi-arid areas, because this species could produce more hydrophobic

substances into the soil than other species. However, Liu et al. [35] found that broadleaved forests can most obviously improve soil quality, followed by broadleaved coniferous mixture and coniferous plantations. In addition, Nie et al. [27] found plant species had no significant impact on soil organic carbon concentration. Cao et al. [32] also found that the differences of soil nutrients between black locust and Chinese pine were not obvious.

Afforestation has been seen as an important role to reduce soil erosion and improve soil quality, which is usually expressed by the content of soil organic carbon (SOC) or soil organic matter (SOM). Many parameters including bulk density and aggregate stability correlated well with SOC or SOM. Aggregate stability, indicating soil structural stability, is often considered as an important soil quality [8]. It was believed that the SOC content played an important role in the soil aggregation [27]. In addition to, aggregate size distribution and stability can also be used to indicating of soil degradation [1]. Mean weight diameter (MWD) of water stable aggregates has been recognized as an important indicator on the capability of the soil to resist against water erosional forces. Meanwhile, stable aggregate played an important role in the stabilization of SOC [33]. Micro-aggregates are bound together by young organic matter into larger macro-aggregates and a breakdown of macro-aggregates results in a release of labile SOM [4]. It is generally accepted that the stability of SOC in soil aggregates is closely related to the protection of aggregate structure from microbial decomposition [33].

The focus of afforestation changed to carbon stocks in the last decades [15]. Among the numerous sources of greenhouse gases, emissions of CO_2 are affected by changes of land use [23]. Soil carbon consists of soil organic carbon (SOC) and soil inorganic carbon (SIC) [6]. Determining changes in soil organic carbon (SOC) and inorganic carbon (SIC) caused by plantation is important for estimating the regional carbon budget and evaluating ecological effects [30]. The choice of tree species plays an important role in SOC accumulation. The *Populus* plantation was main carbon sink with a carbon sequestration rate of 9.50 t C/ (ha·yr) in Beijing [36]. Li and Liu [25] believed that soil was a great reservoir for C storage in black locust plantation. The quantitative contribution of plantation types to C stocks is much debated. For example, Cao et al. [31] found that the SOC densities of the N-fixing black locust plantations were significantly lower than those of the Chinese pine plantations and secondary oak forests. However, Wang et al. [5] found that after 23 years' growth, N-fixing species performed better in restoring soil carbon. Tong et al. [28] concluded that the total soil C stock in a layer of 100 cm was in the order: *Robinia pseudoacacia* > *Populus tomentosa* > *Caragana korshinskii* in the Loess hill region of China.

Therefore, the objective of the study was to quantifying aggregate stability, organic and inorganic carbon density in soil profiles of *R. pseudoacacia*, *P. tabuliformis* and *M. pumila* plantations. We hypothesized that: (1) plantation type and soil layers would affect soil properties such as soil aggregate stability, soil organic and inorganic carbon content and (2) content of organic carbon and inorganic carbon was different in water stable aggregates with different sizes. The study will contribute to tree species selection in afforestation as carbon sink increase as well as water and soil conservation measures.

Objects And Methods

Study area and soil sampling.

The study area is located in the north of Liquan County situating the south region of Loess Plateau, China (Fig. 1). The mean annual temperature is 12.6℃ with the highest monthly temperature in July (34℃) and the lowest in January (-4℃) and with 214 frost-free days. The mean precipitation is 517.6 mm. After level-terrace site preparation on the same slope, *Robinia pseudoacacia* and *Pinus tabuliformis* were planted fifty years ago, *Pinus tabuliformis* plantation is above *Robinia pseudoacacia* plantation. And the *Malus pumila* plantation was planted thirty years ago at the level ground on bottom of the slope. The studied soil is named cinnamon soil in the Chinese genetic classification [37], which has been developing from loess parent material. The mean diameter at breast height (DBH) of *Malus pumila*, *Robinia pseudoacacia* and *Pinus tabuliformi* was 12.98 cm, 12.73 cm and 15.42 cm respectively, the average pH of surface soil under the site of them is 8.42, 8.33 and 7.97 respectively. During September 2018, a plot was chosen in the central area of each plantation, in which three soil profiles were digged into 50 cm (in *Malus pumila* plantation) or 80 cm (in *Robinia pseudoacacia* and *Pinus tabuliformis* plantations) with intervals of 10 cm using a spade for sampling. Soil samples were air-dried for one-week and stored at room temperature.

Experimental design.

5–10 g dry aggregates with 2–5 mm diameter were gently submerged into distilled water for 30 minutes and then washed onto a 0.05 mm sieve using ethyl alcohol. After shaking with hands about 15 times all soil particles with different diameters were washed into a 200 mL beaker using ethyl alcohol, and separated by moving a cascade of sieves with openings of 5, 2, 1, 0.5, 0.2, 0.1 mm after drying at 40℃.The water stable aggregates with the diameters of < 0.1 mm, 0.1–0.2 mm, 0.2–0.5 mm, 0.5-1.0 mm,1.0–2.0 mm and > 2.0 mm were weighed and mass percentages were calculated [34]. The treatment was replicated three times.

SOM concentrations of the aggregate fractions and the bulk samples were determined using the oil bath-$K_2Cr_2O_7$ titration method. Bulk density was measured with a standard technique using a cutting ring driven vertically downward into the midrange of each horizon. The content of inorganic carbon was determined by volume of carbon dioxide from reaction with hydrochloric acid [14].

Data analysis.

Mean weight diameter (MWD) was calculated using the following formula. Where $\overline{X_i}$ (in millimetre) is a mean diameter of two consecutive sieves, and w_i is corresponding mass percent.

$$MWD = \frac{\sum_{i=1}^{6} \overline{x_i} w_i}{\sum_{i=1}^{6} w_i} \qquad (1)$$

Soil organic carbon density (hereafter: SOCD) and soil inorganic carbon density (hereafter: SIOCD) at different soil layers were computed using the following equations:

$$SOCD(i) = \frac{SOC(i) \times BD(i) \times H(i)}{10}$$

$$SIOCD(i) = \frac{SIOC(i) \times BD(i) \times H(i)}{10} \qquad (2)$$

Where SOC (i) and SIOC (i) is the content of SOC(%) and 0.12* $CaCO_3$(%) in the layer i respectively, BD(i) is the soil bulk density (g/cm^3) in the layer i, H(i) is the soil layer's thickness(10 cm).

The diagrams in the paper were drawn with ggplot2 packages of R [20] and Excel 2013. SPSS software (version 16.0) (SPSS Inc., Chicago, IL, USA) was used to perform the statistical and variance analyses. One-way ANOVA followed by LSD's test was used to compare the significance of difference of MWDs among the different soil layers under the same plantation and among the three plantations at the same soil layer. An independent t-test was used to test the differences between *R.pseudoacacia* and *P. tabuliformis* plantations in the 50-80cm soil layers.

Results

Aggregates stability characteristics.

Plantation types influenced significantly the MWDs of soil water stable aggregates (Fig. 2). MWD was 0.18–0.27 mm, 0.35–0.57 mm and 0.11–0.15 mm under *R.pseudoacacia*, *P. tabuliformis*, and *M.pumila* plantations respectively. The MWD among three plantations differed significantly at all soil layers. The MWD of *P. tabuliformis* was 22–67% greater than that of *R. pseudoacacia* across the 0–80 cm layers with 10 cm intervals. MWD was 39% and 70% higher in *R. pseudoacacia* and *P. tabuliformis* than in *M.pumila* across 0-50cm layers. The variation characteristics of MWD in soil profile under three types of plantation were different. The MWD of 20-80cm is higher than that of 0-20cm under the *P. tabuliformis* plantation. The MWD of 0-10cm was the highest, followed by 10-30cm, and that of 30-80cm was the lowest under *R. pseudoacacia* plantation. The MWD did not differ significantly at all layers under *M.pumila* plantation.

The content of SOC and calcium carbonate ($CaCO_3$).

Our findings showed that 26%, 31% and 31% of SOC were distributed in the top soil (0–10 cm) in *P. tabuliformis*, *R. pseudoacacia* and *M.pumila* plantations respectively. Meaningwhile, the differences of SOC content were smaller in the subsurface layers (10–60 cm) than in the surface layer (0–10 cm) between plantations of *R.pseudoacacia* and *M.pumila*. However, in all soil layers, the SOC content was significantly the highest in the *P. tabuliformis* plantation than in the *R. pseudoacacia* and *M.pumila* plantations (Fig. 3A). The percentage of calcium carbonate ($CaCO_3$) was expressed in Fig. 3B. The content of $CaCO_3$ varied from 19–23% in *R. pseudoacacia* plantation, from 12–14% in *M.pumila* plantation, and from 3–10% in *P. tabuliformis* plantation, showing the order of *R. pseudoacacia* > *M.pumila* > *P. tabuliformis*. The content of $CaCO_3$ in *R. pseudoacacia* plantation was 2.22–5.67 times that of *P. tabuliformis* plantation in different soil layers. $CaCO_3$ content varied among the three forest types—despite all soils been developing over loess parent material rich in carbonate materials—mainly due to plantation types.

Bulk density characteristics.

The bulk density varied between 1.41 g/cm^3 and 1.56 g/cm^3 in the *M.pumila* plantation, between 0.91 g/cm^3 and 1.31 g/cm^3 in *P. tabuliformis* plantation, and from 1.16 g/cm^3 to 1.48 g/cm^3 in *R. pseudoacacia* plantation (Fig. 3C). Bulk density was always higher in *M.pumila* plantation than in the two others in the whole soil layers.

Soil organic carbon density and soil inorganic carbon density.

At the soil profiles, soil organic carbon density (SOCD) was the highest at the surface soil and the distribution pattern was similar to SOC. Soil inorganic carbon density (SIOCD) increased gradually to a maximum value and then declined step by step. However, the peak was attained at different soil layer under the three plantations (Fig. 3D). The average SOCD and SIOCD were 0.97 kg/m^2 (SD = 0.46) and 3.51 kg/m^2 (SD = 0.44) under *R.pseudoacacia* plantation, 1.58 kg/m^2 (SD = 0.49) and 1.06 kg/m^2 (SD = 0.34) under *P. tabuliformis* plantation, 1.06 kg/m^2 (SD = 0.43) and 2.40 kg/m^2 (SD = 0.20) under *M.pumila* plantation. Soil total carbon density (STCD) was calculated by SOCD plus SIOCD (Fig. 4). The ratios of SOCD to STCD were 15–44%, 45–88%, 24–47% in *R. pseudoacacia*, *P. tabuliformis*, *M.pumila* plantations respectively. STCD was the highest at the *R. pseudoacacia* plantation, intermediate at *M.pumila* plantation, and the lowest at *P. tabuliformis* plantation (Fig. 4). The STCD fluctuated with deepening soil layers. The STCD were 59%, 68%, 73%,48%, 64%, 84%, 100%, 74% higher in the 0–10,10–20, 20–30, 30–40, 40–50, 50–60, 60–70 and 70-80cm successively of *R. pseudoacacia* forest than that of *P. tabuliformis* forest. The STCD were 30%, 46%, 33%, 24%, 3%, 22% higher in the 0–10, 10–20, 20–30, 30–40, 40–50, 50-60cm of *M.pumila* forest than that of *P. tabuliformis* forest.

The content of soil organic matter and inorganic carbon in water stable aggregate with different size.

The $CaCO_3$ content declined successively with increasing aggregate size and was the lowest in > 2 mm fraction (Fig. 5). Inversely, the SOM content increased linearly with the increase in aggregate size, and the highest was in > 2 mm fraction (3.93%) (Fig. 5). It was obvious that there was a tradeoff between SOM and $CaCO_3$ content.

Discussion

An evaluation of the changes in soil properties as a consequence of forest planting is important, especially for fragile ecological areas [2]. Our results supported the hypothesis that bulk density, aggregates stability and the content of carbon were affected by tree species, and they also changed obviously among different soil layers. Additionally, water stable aggregates with bigger sizes had more soil organic matter content, but less calcium carbonate content. According to the *Kyoto protocol*, forest planting is an important action to build a soil carbon pool in terrestrial ecosystems [21]. The total carbon density was in the order of *R. pseudoacacia* > *M.pumila* > *P. tabuliformis* in all soil layers. Compared with *M. pumila* and *P. tabuliformis* plantations, *P.tabuliformis* plantation was more conducive to accumulation of soil organic carbon, decrease of soil inorganic carbon and bulk density, and then could improve the water stability of soil aggregates, which will facilitate the improvement of soil quality and protection of soil and water from loss.

Changes in soil properties among three plantations.

Soil aggregate stability is considered to be a property that provides information on soil quality [11]. In addition, many studied soil parameters aligned with SOC [8], especially such as aggregate water stability. It was observed that water stability of soil aggregates and SOC content both were in the order of *P. tabuliformis* > *R. pseudoacacia* > *M.pumila*, indicating that soil quality and related soil functions varied greatly among three plantations. Similarly, Chen et al. [13] found that soil organic carbon was higher in 10-year-old *P. tabulaeformis* than in 10-year-old *R.pseudoacacia* stands. In our study, it was demonstrated that *P. tabuliformis* would be more conducive to increase of SOC and improvement of aggregate stability compared with *R. pseudoacacia* and *M.pumila*. This is in agreement with results found by previous studies, which observed *Pinus* plantation could supply soil with considerably more organic material and improve water repellency of soil [3, 22]. Increase in SOC was mostly associated with an increase in soil hydrophobicity, especially under the wax/aromatic oil rich litter of the *Pinus halepensis* trees [9]. Moreover, the presence of water repellency can play an important role in the formation and stabilization of aggregates and can avoid high levels of soil degradation [11]. From this, it seemed logical that soil quality indicators including SOC and aggregate stability have been improved by *P. tabuliformis* plantation in the present study. Additionally, the fine root biomass (FRB) and fine root production (FRP) of

P.tabulaeformis were greater than those of *R. pseudoacacia* [13]. Small and fine roots produced optimal conditions to form and stabilize aggregates due to the polysaccharides being produced by the microorganisms [1]. Meanwhile, BD was significantly related to most other soil parameters and it could be used as an indicator of soil structure [2]. The soil BD was in the order of *P. tabuliformis* < *R. pseudoacacia* < *M.pumila*, which indicated there was negative variation trend between BD and MWD or SOC. Our study demonstrated that the increase of SOC corresponded to the improvement of aggregate stability and decrease of BD, which was most significant in *P. tabulaeformis* plantation, and *R. pseudoacacia* plantation followed. At *M. pumila* plantation, MWD of water stable aggregates was the smallest (Fig. 2), which was similar with the lowest SOC (Fig. 3A). It was visible that *M.pumila* plantation had the lowest values of SOC and MWD, but the highest bulk density. This could be explained by long term cultivation management such as pruning and weed control resulting in the lower input and higher decomposition of organic substances. Lal [21] also believed that most soil under the managed ecosystems contained a lower SOC pool than their counterparts under natural ecosystems due to the depletion of the SOC pool in cultivated soil. Our findings also showed that soil organic matter was largest significantly in the surface layer (0–10 cm) compared to the other soil layers. This was in agreement with previous studies conducted in other forest ecosystems [24], and was a logical result as the surface layer is the main place of soil organic matter sources such as dry branches and fallen leaves.

Effects of tree species on soil carbon sequestration.

It is also becoming increasingly clear that carbon accumulation in soil represents an important carbon stocks [24]. The quantitative relationship between the changes of SOC and SIC stocks in deep profiles following vegetation restoration should be further determined [30]. Our results showed SOCD ranged from 0.64–2.63 kg/m^2 and SIOCD ranged from 0.37–4.08 kg/m^2 over the 0–80 cm soil profiles. Compared with *P. tabulaeformis*, The STCD increased by 59%-100% and 3% -46% in *R. pseudoacacia* and *M. pumila* plantations respectively. SIOCD to STCD ratios in *R. pseudoacacia* and *M. pumila* plantations were 56–85% and 53–76%. Zethof et al. [8] and Wang et al. [29] also found inorganic carbon content was often much larger than that of organic carbon in semi-arid regions. SIOCD to STCD ratios were lower (12%-55%) under *P. tabulaeformis* plantation, which was due to coniferous trees having more acid exudate compared with broadleaf trees. And then, more carbonate would be dissolved [29]. In addition, higher organic matter accumulation under *P. tabulaeformis* plantation increased saturated hydraulic conductivity [2], which also increased carbonates leaching. The content of $CaCO_3$ and SIOCD fluctuated with deepening soil layers, showing there was more inorganic carbon content in subsoils. Han et al. [30] also confirmed that the maximum soil in-organic carbon (SIC) values was at 60–100 cm soil layer. SIC content at subsoil increased significantly due to the dissolution and leaching of carbonates from topsoil and the subsequent precipitation in subsoils [6]. There was a lot more carbon in deep soil than we once thought, and the underlying processes inhibiting its turnover are still largely unknown [17].

Aggregate-$CaCO_3$ content decreased with increasing aggregate size.

In many semi-arid regions, where the presence of carbonates in soil is frequent, it is necessary to study the correlation between carbonates and aggregate stability. For example, Fernández-Ugalde et al. [19] thought carbonates must be considered when modelling soil structure formation. Calcium bridging is the dominant factor for the long-term positive effect of calcium addition on the structural stability of soil [10]. Chrenková et al. [11] found carbonate content had a positive influence in MWD for sandy soils. In semi-arid calcareous soils, Fernández-Ugalde et al. [19] found that the interaction of maize straw and carbonates resulted in a higher stability of macro-aggregates (> 250um) in carbonated soil than non-carbonated soil, then concluded the formation of secondary carbonates within and/or around macro-aggregate could explain this stability. In our case, the effect of carbonates in stabilization of aggregates showed two-sidedness. On the one hand, aggregate-inorganic carbon decreased with increasing aggregate size, except for the smallest size which had lower concentration than the next-bigger size. This occurred because the $CaCO_3$ could make the soil particles consolidated in the dry state. But when soil was wetted by water, the $CaCO_3$ could dissolve in water and make the soil particles separated and become dispersed. Therefore, the aggregates of calcareous soil were easily broken under the fast wetting condition. Our study also found that *P. tabulaeformis* could effectively decrease the content of $CaCO_3$, which lead to the improvement of soil stability and reducing of soil erosion. On the other hand, there was a linear positive correlation between inorganic carbon content and MWD of water stable aggregates in the soil profile of *P. tabulaeformis* plantation, while a linear negative correlation was found in the soil profile of *R. pseudoacacia* plantation (Fig. 6). Therefore, this paper assumed that there was a threshold value of inorganic carbon content in soil. When it was higher than the threshold value, the aggregate structure would be destroyed with the dissolution of calcium carbonate in the process of rapid wetting; when it was lower than the critical value, calcium carbonate could be used as aggregate cement. Uddivira et al. [16] found that adding Ca^{2+} to the soil with Ca^{2+} concentration of 2.7 and 3.1cmol/kg increased the percentage content of water stable aggregates, on the contrary, adding Ca^{2+} in the soil with Ca^{2+} concentration of 13.9 cmol / kg would disperse more aggregates. Virto et al. [7] also believed that compared with the soil with 30% carbonate content, the carbonate in the soil with 15% carbonate content played a major cementation role in soil aggregates.

Aggregate-SOM content increased with increasing aggregate size.

Qiao et al. [33] suggested that micro-aggregates played key roles in protecting SOC based on more recalcitrant SOC stored in micro-aggregates. However, higher organic carbon content in the macro-aggregates (> 2 mm fraction) compared to the micro-aggregates (0.2 mm fraction) in our results, that was similar to previous studies [19], which observed that when organic inputs were increased in a

calcareous soil, a greater proportion of stable macro-aggregate (> 250um) would be formed in comparison to a non-calcareous soil of similar characteristics. Gao et al. [18] also found the largest amount of organic carbon was stored in > 0.25 mm size aggregates. Elliott [4] observed more organic matter associated with macro-aggregates than with micro-aggregates in a temperature grassland soil. The conclusion also was line with the theory of aggregate hierarchy, which believes an increase in carbon concentration with increasing aggregates size class because that large aggregate-size classes are composed of small aggregate-size classes plus organic binding agents [4]. In general, there was a trade-off between SOC and $CaCO_3$, which was similar to the conclusions of Yang et al. [6] and Han et al. [30].

Conclusions

Organic materials are the major cementing agents influencing aggregation formation and stabilization. Calcium carbonate may be a dispersing agent when it was higher than a threshold value. On the contrary when it was lower than the threshold value, it could be used as aggregate cement. Soil organic carbon and inorganic carbon were affected by tree species. The economic forest *M. pumila* decreased the content of SOM and MWD of water stable aggregates due to effect of management. *M. pumila* and *R. pseudoacacia* were not as beneficial as *P. tabulaeformis* for the sequestration of SOC and improving water stable aggregates.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

The authors agree to publication in the journal.

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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Authors' contributions

Dong Lili contributed to study design, literature research, data analysis, statistical analysis and manuscript preparation. Kou Meng contributed to manuscript editing and revision.

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Figures

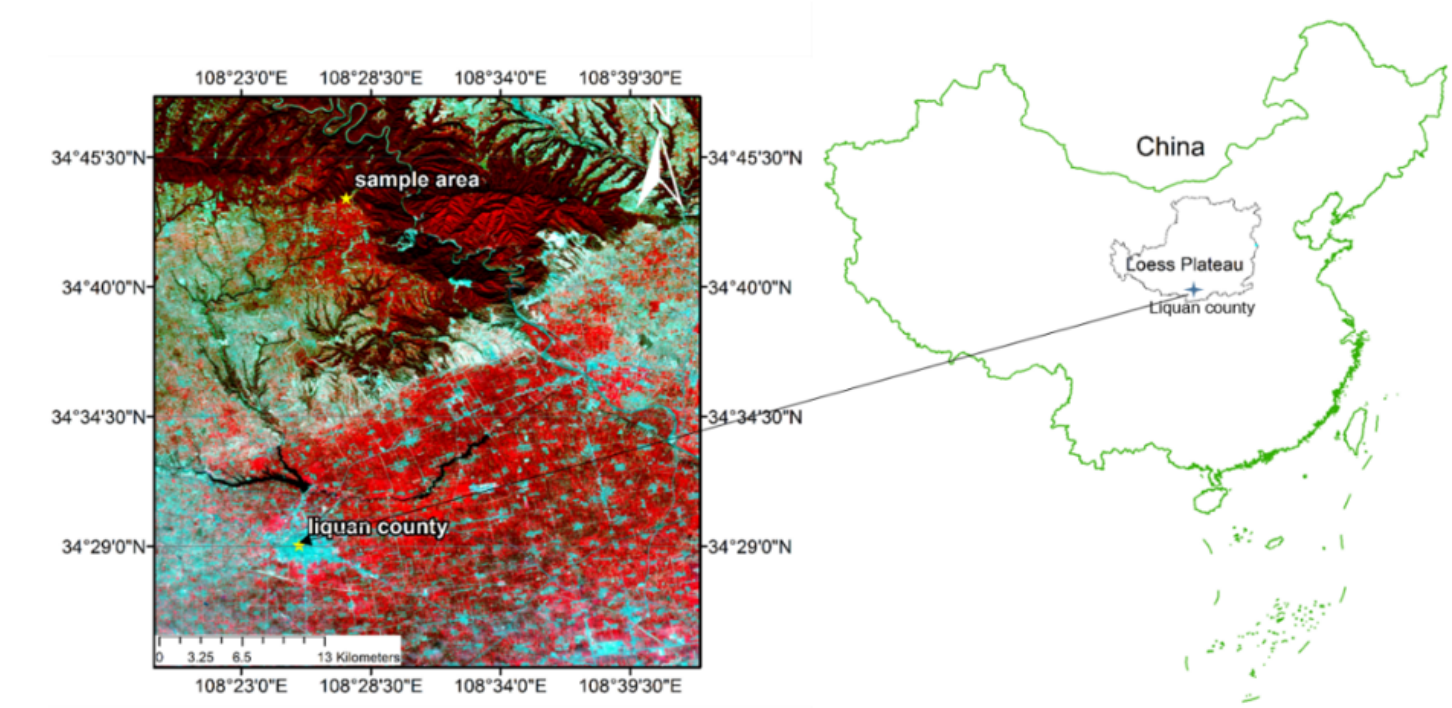


Figure 1

The location of sample area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

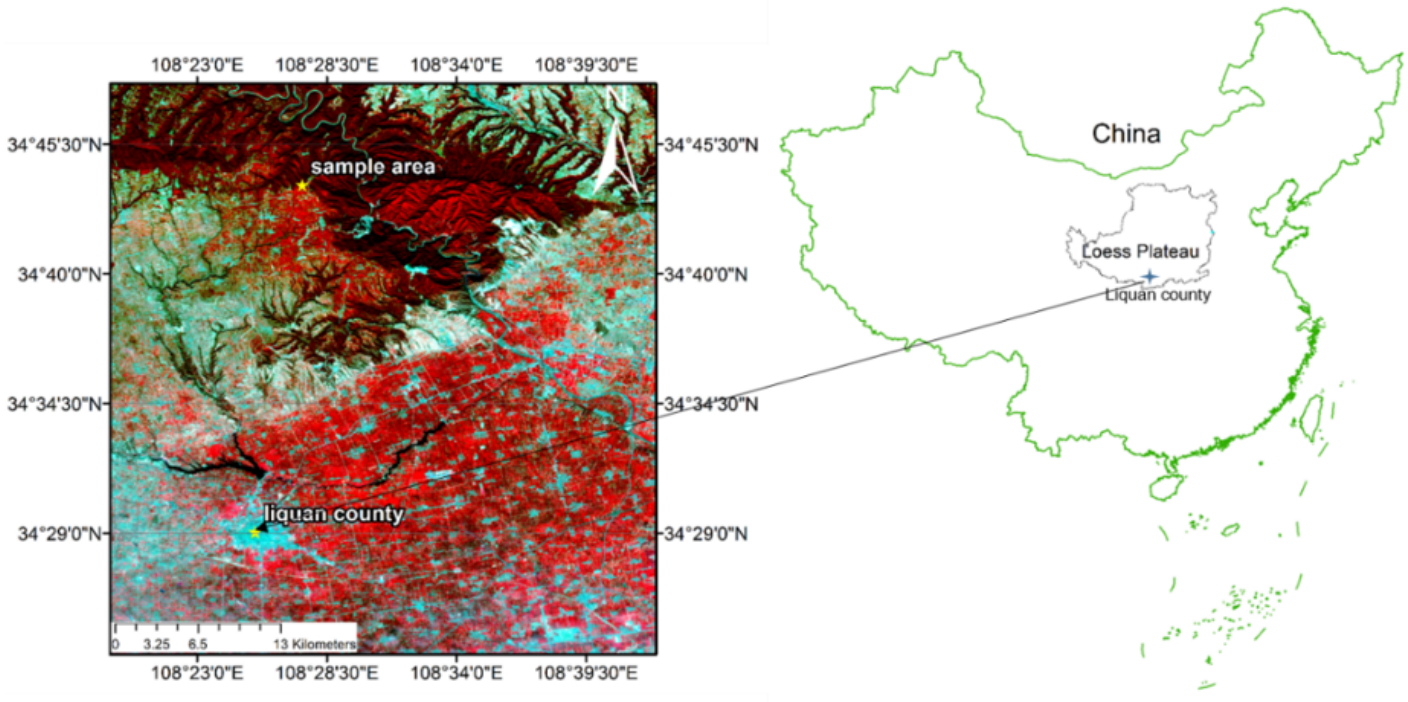


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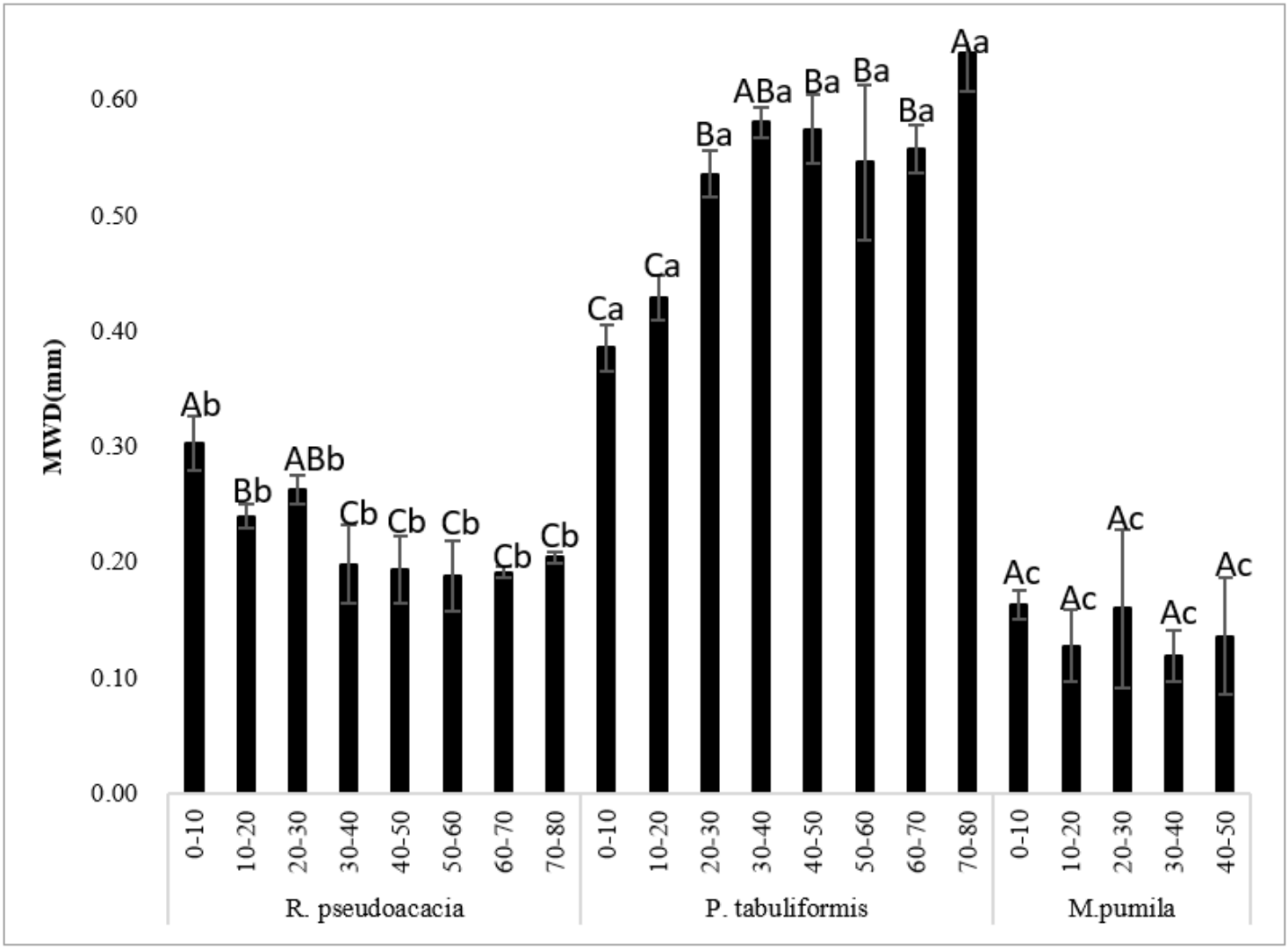


Figure 2

The MWDs of water stable aggregates under several soil layers in the three plantations Notes: The different capital letters mean differences are significant among the different soil layers under the same plantation ($p<0.05$). The different lowercase letters mean differences are significant among the three plantations at the same soil layer ($p<0.05$). Error bars represent standard error.

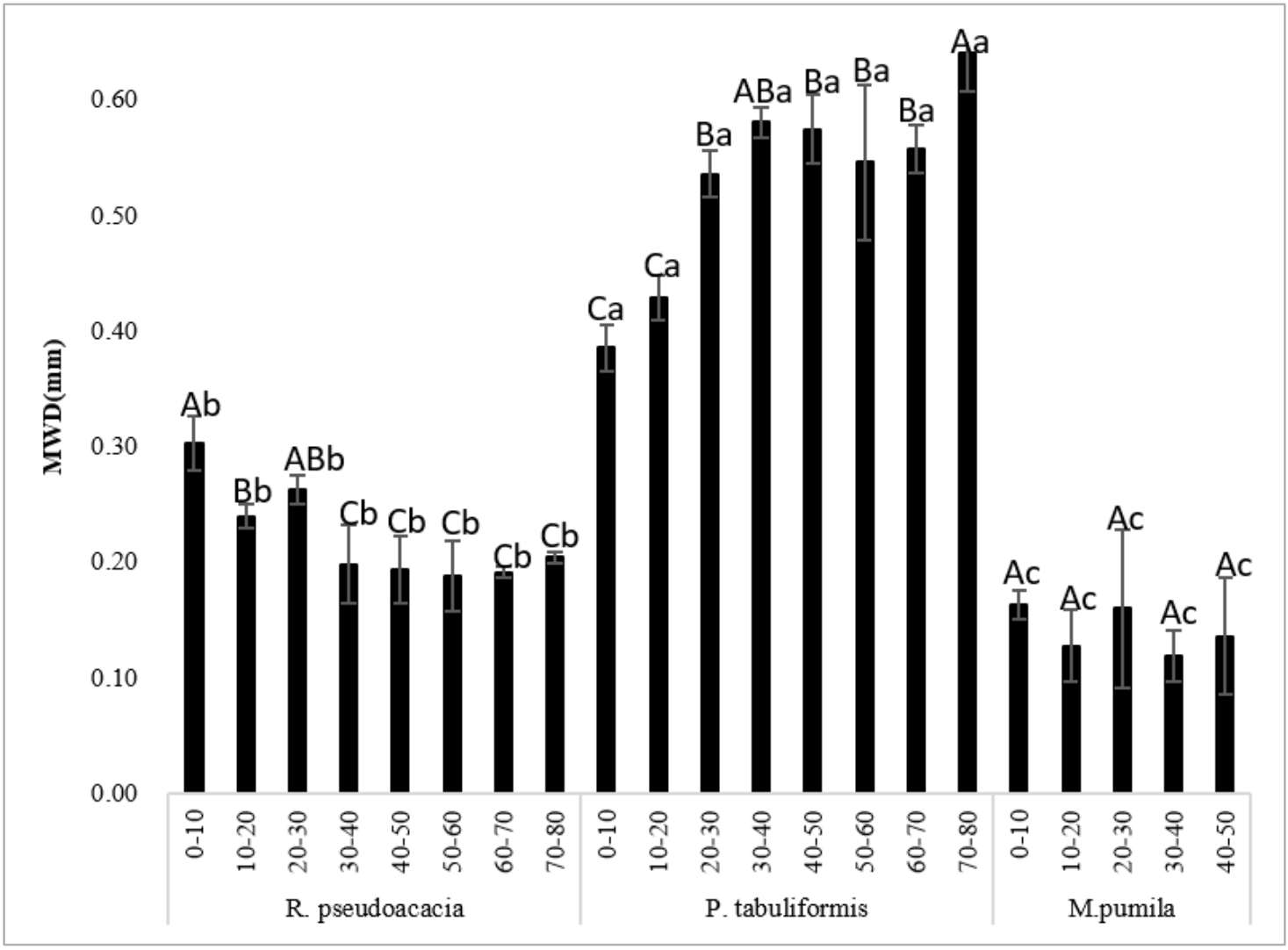


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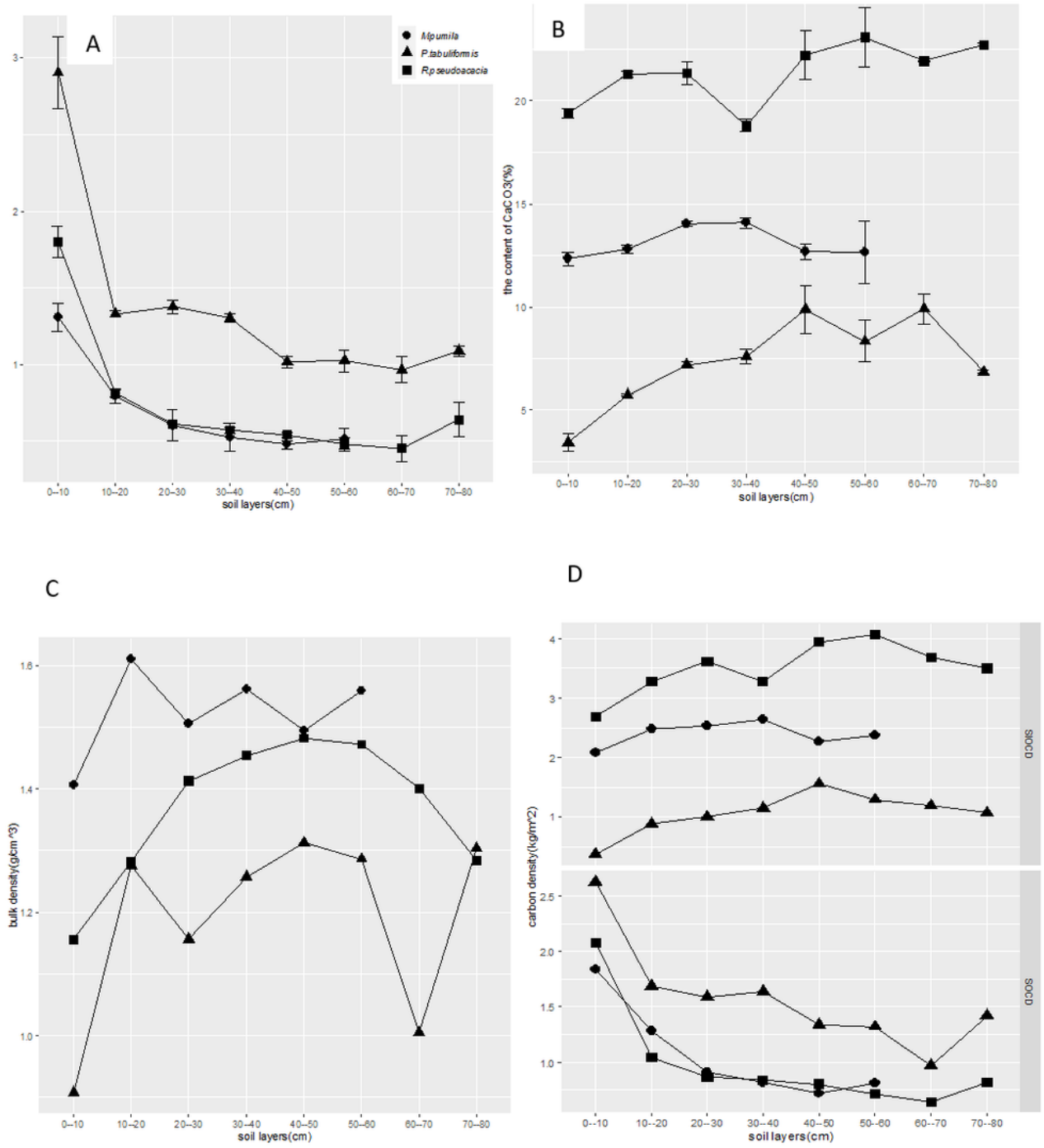


Figure 3

The content of soil organic matter (A), CaCO3 (B), bulk density (C) and carbon density (D) under several soil layers in three artificial forest types

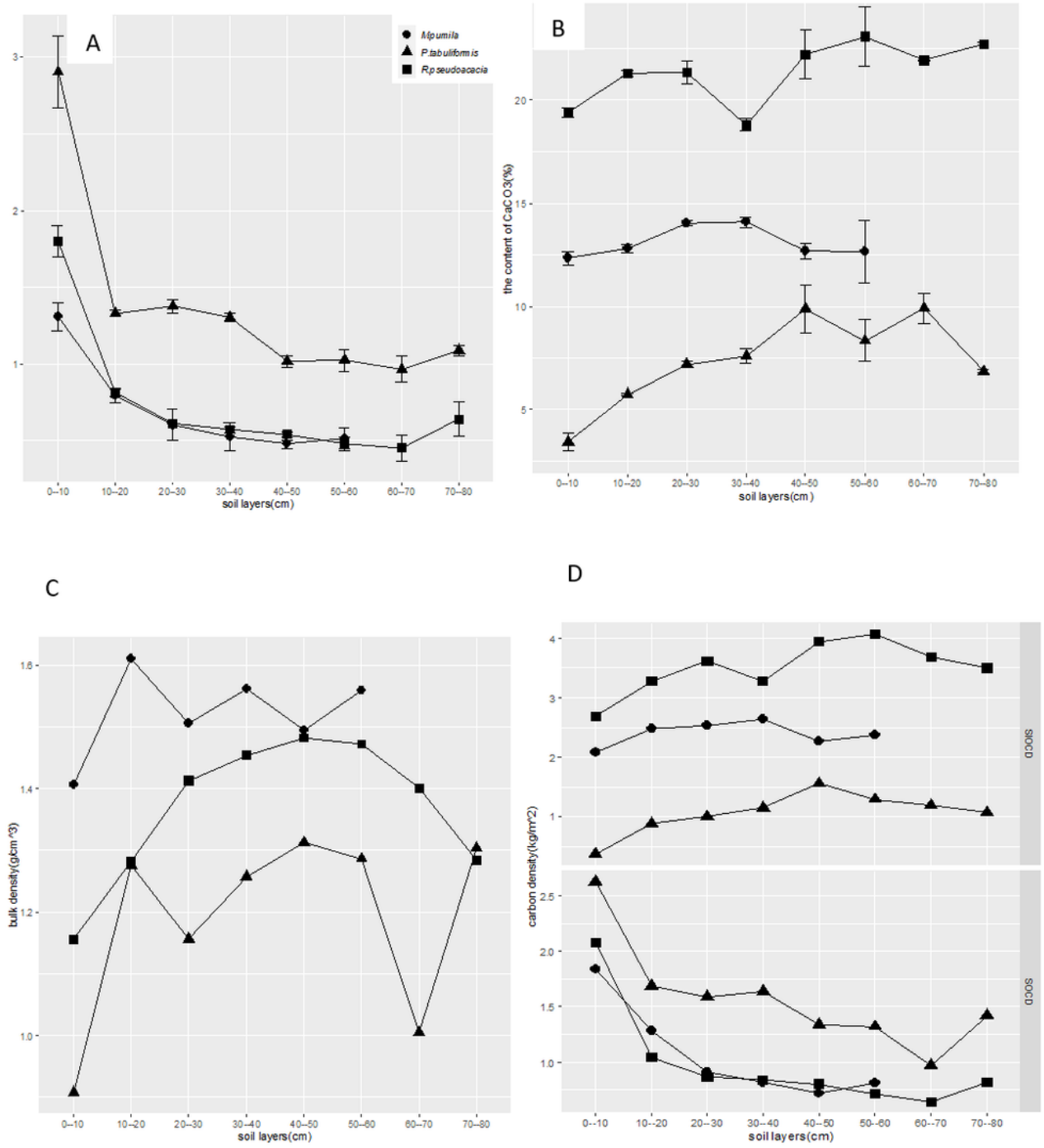


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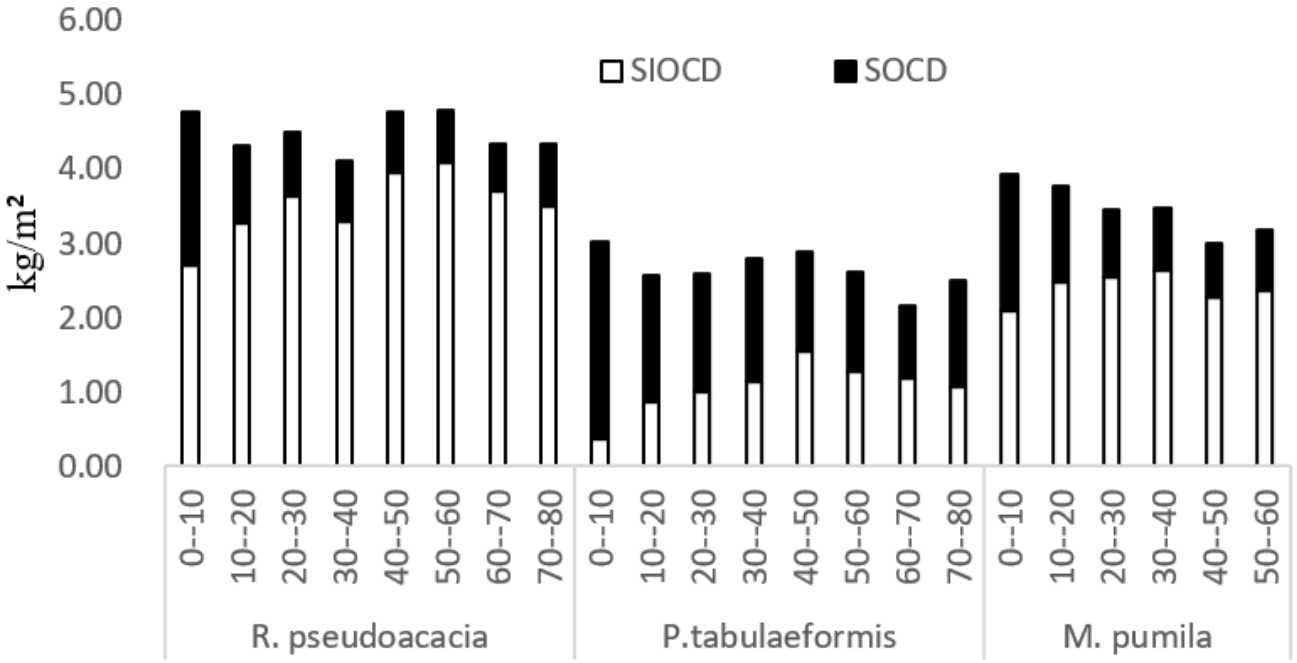


Figure 4

Soil total carbon density under several soil layers in three artificial forest types

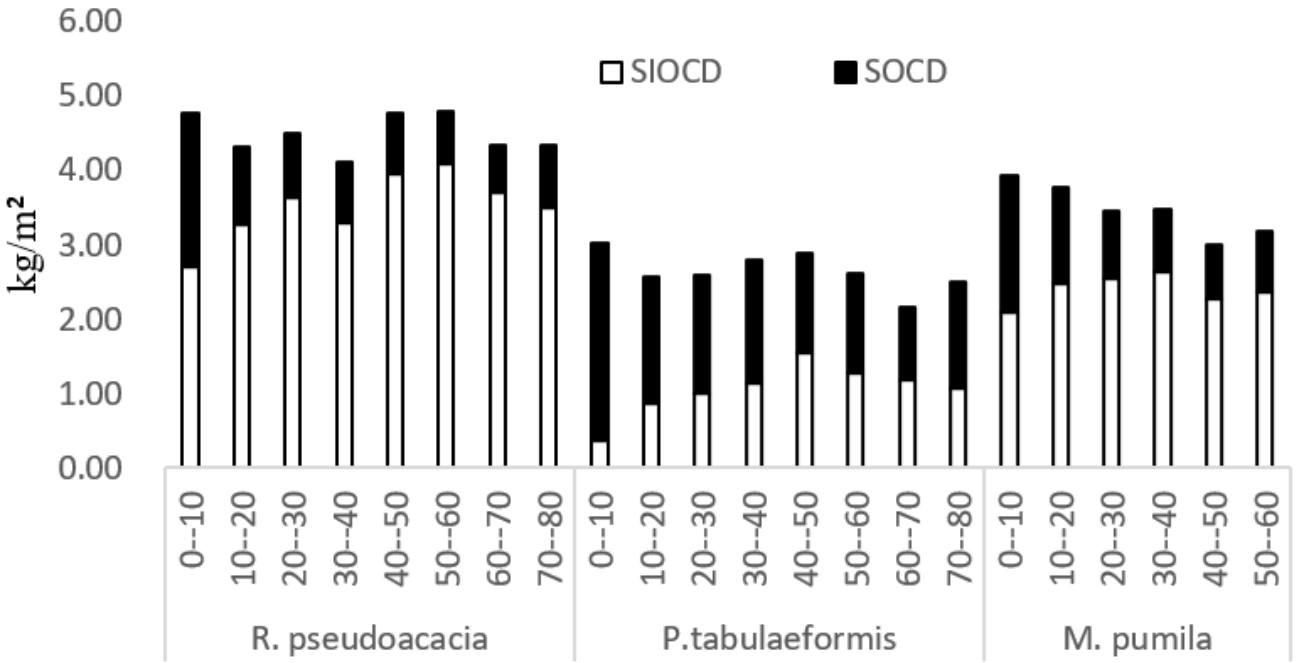


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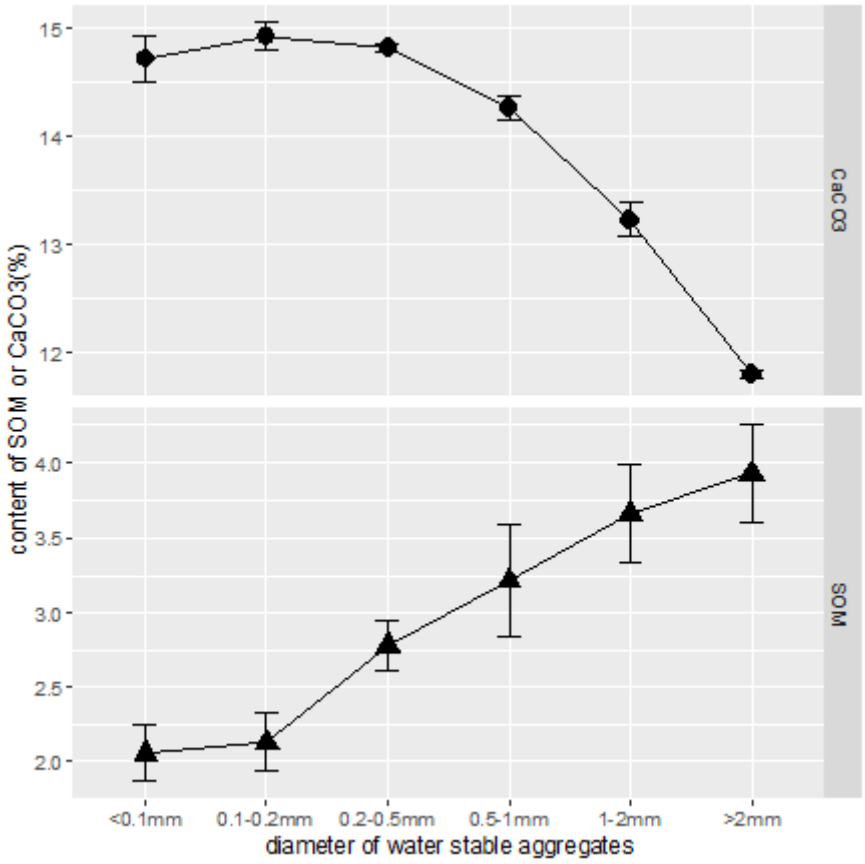


Figure 5

The content of calcium carbonate (CaCO3) and soil organic matter (SOM) in water stable aggregates with different sizes

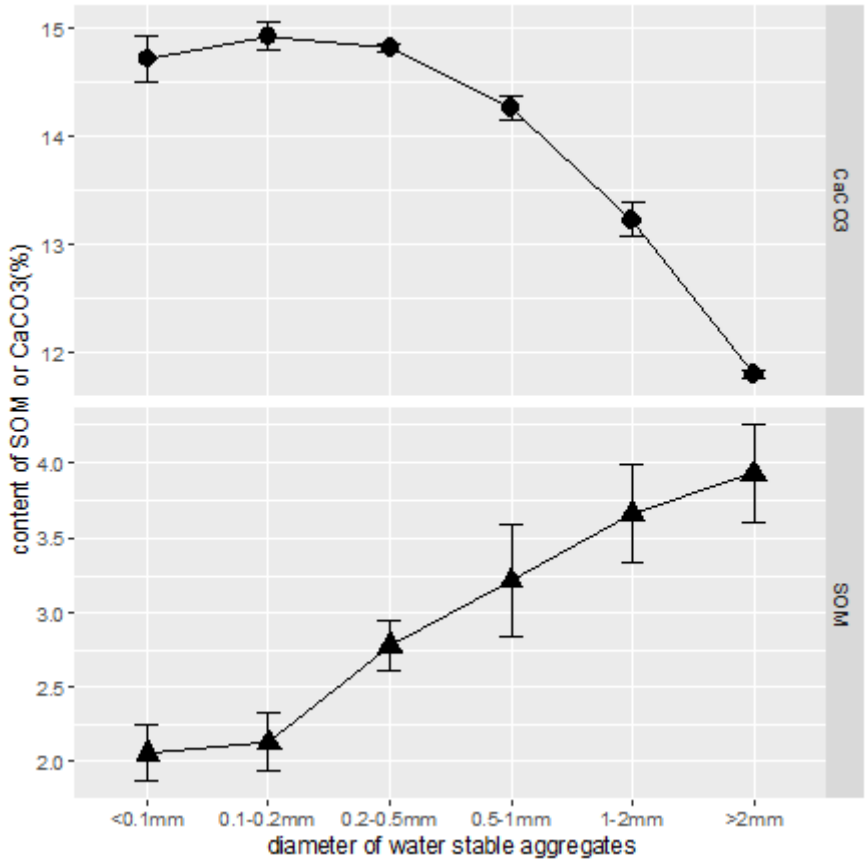


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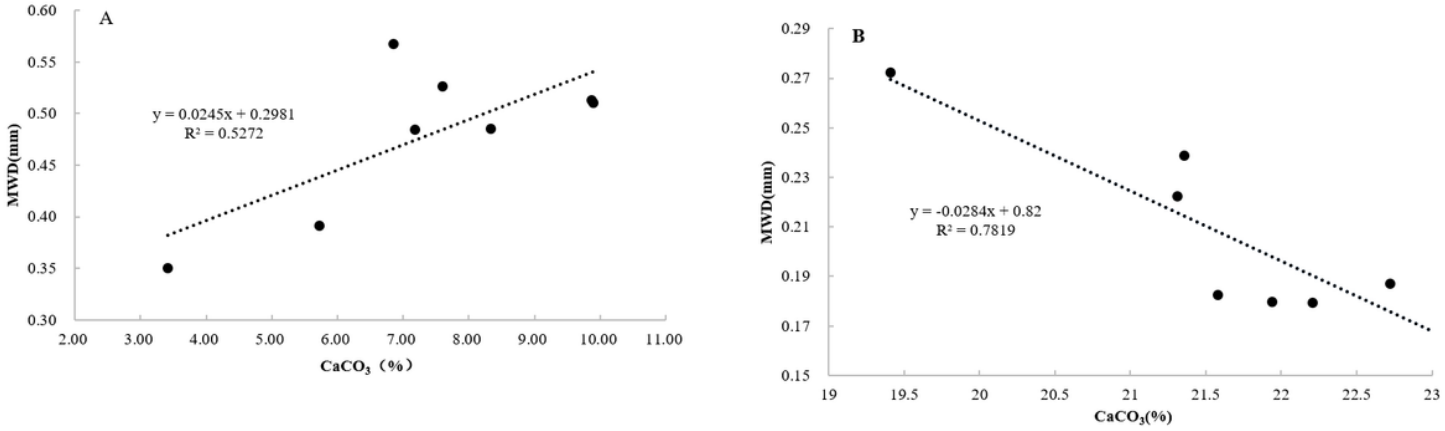


Figure 6

Relationship between MWD of water stable aggregates and CaCO3 content in Pinus tabulaeformis (A) and Robinia pseudoacacia (B)

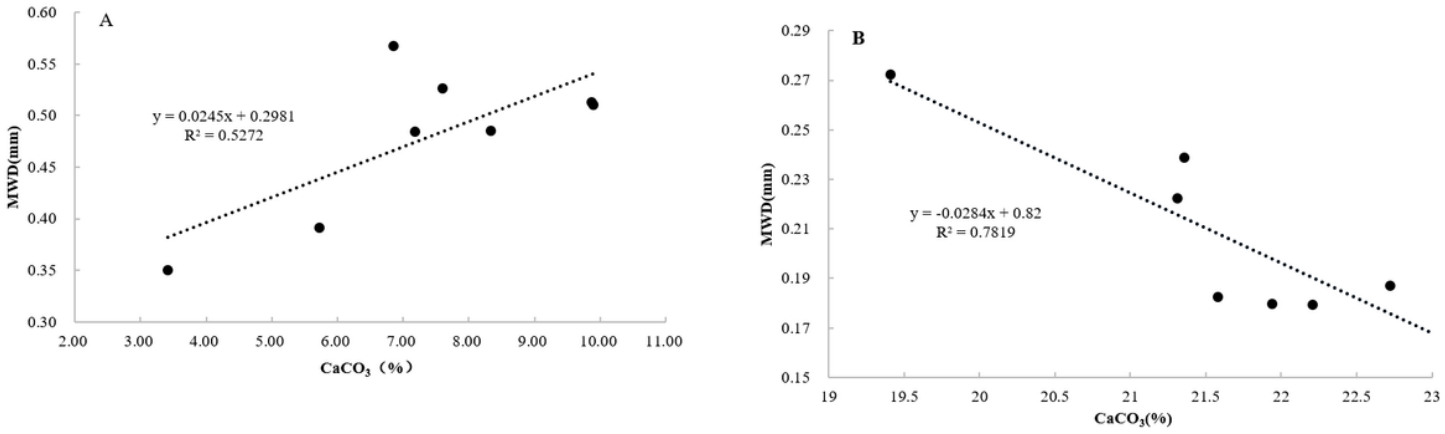


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