Quantifying the interactive effects of organic matter and charged soil particles on aggregate stability following natural vegetation restoration

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Abstract

Vegetation restoration can input amounts of organic matter into soils to improve soil aggregate stability; for this process, the interaction between organic matter and charged soil particles is a key. However, the molecular-scale knowledge about organic matter-mineral interactions remains largely qualitative. Here, we analyzed soil particles surface electrochemical properties and soil internal forces (electrostatic, hydration , and van der Waals forces) along vegetation restoration to quantitatively evaluate how SOM increase the stability of soil aggregate. Our results revealed that the enrichment of SOM after revegetation increased the cation exchange capacity (CEC), specific surface area (SSA), and soil surface charge density ($\sigma 0$), thereby strengthening the electrostatic repulsive pressure. Besides, the increasing SOM led to the increase in Hamaker constant at the molecular level and thus enhanced the van der Waals attractive force. As a result, the net pressure of soil internal forces was repulsive and decreased with increasing SOM during vegetation restoration. Meanwhile, the net pressure increased first and then leveled off with the decrease of electrolyte concentration in the bulk solution. The determined soil aggregate breaking strength showed similar trends to that of net pressure. Soil aggregate stability under different succession stages followed the order of farmland < grassland < shrub < forest. Overall, the experimental results of soil aggregate stability were in excellent consistent with the theoretical predictions of soil internal forces. Consequently, we conclude that organic matter input during vegetation restoration increased aggregate stability mainly due to the decrease of the repulsive net pressure of soil internal forces.

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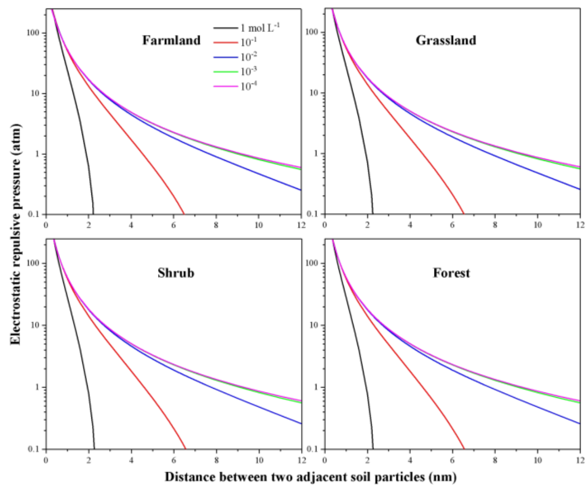
Farmland
Grassland
Shrub
Forest
1 mol L⁻¹
10⁻¹
10⁻²
10⁻³
10⁻⁴
Electrostatic repulsive pressure (atm)
Distance between two adjacent soil particles (nm)

Fig. 1.

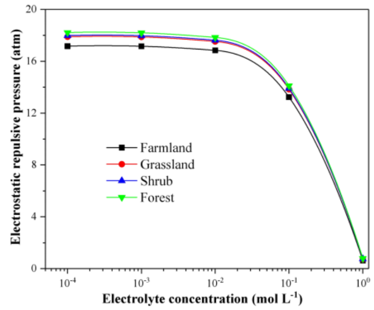
Electrostatic repulsive pressure (atm)
Electrolyte concentration (mol L-1)
Farmland
Grassland
Shrub
Forest
20
16
12
8
4
0
10-4
10-3
10-2
10-1
100

Fig. 2.

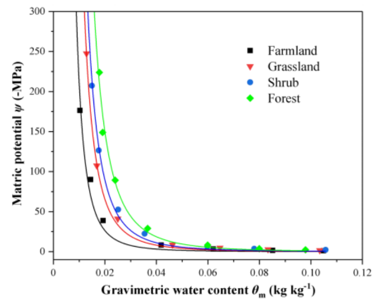
Matric potential ψ (-MPa)
Gravimetric water content θm (kg kg-1)
Farmland
Grassland
Shrub
Forest
0
50
100
150
200
250
300
0
0.02
0.04
0.06
0.08
0.10
0.12

Fig. 3.

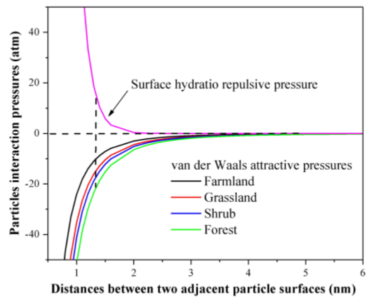
Surface hydratio repulsive pressure
van der Waals attractive pressures
Farmland
Grassland
Shrub
Forest
Particles interaction pressures (atm)
Distances between two adjacent particle surfaces (nm)
40
20
0
-20
-40
1
2
3
4
5
6

Fig. 4.

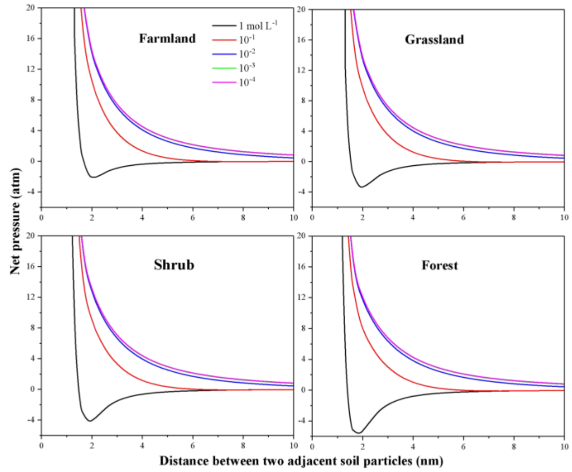
Farmland
Grassland
Shrub
Forest
1 mol L-1
10-1
10-2
10-3
10-4
Net pressure (atm)
Distance between two adjacent soil particles (nm)

Fig. 5.

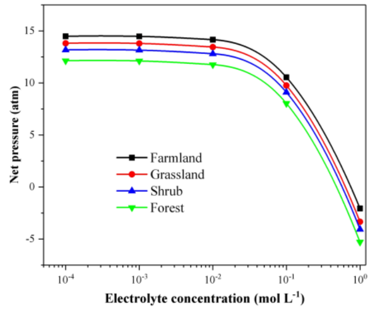
Net pressure (atm)
Electrolyte concentration (mol L-1)
Farmland
Grassland
Shrub
Forest
15
10
5
0
-5
10-4
10-3
10-2
10-1
100

Fig. 6.

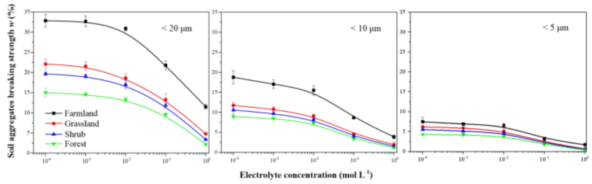
Soil aggregates breaking strength w (%)
< 20 μm
< 10 μm
< 5 μm
Farmland
Grassland
Shrub
Forest
Electrolyte concentration (mol L-1)

Fig. 7.

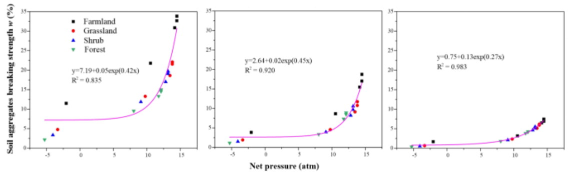
Soil aggregates breaking strength w (%)
Farmland
Grassland
Shrub
Forest
y=7.19+0.05exp(0.42x)
R² = 0.835
y=2.64+0.02exp(0.45x)
R² = 0.920
y=0.75+0.13exp(0.27x)
R² = 0.983
Net pressure (atm)

Fig. 8.