Researches on Ecological Solidification and Melioration Effects of Plants on Silty Soft Soil

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Abstract: Dredged soil from river and lake is a typical silty soft soil, which has a high potential for farmland utilization. However, the newly dredged soil generally has high water content and poor engineering properties, therefore, it must be dehydrated and solidified before utilization. The traditional dehydration and solidification methods have disadvantages such as high energy consumption and secondary pollution risk. A method of soil solidification and amelioration by using plants is explored in this research. Four species of Pennisetum hyridum, Sorghum bicolor × Sorghum sudanense, Typha angustifolia, and Zea mays, were used as the research objects, planted in silty soft soil. The solidification and amelioration effects of different plants were studied by observing the changes in soil mechanics and physicochemical properties before and after the experiment. The results showed that: all the four tested species showed soil solidification effects in different degrees, the Pennisetum hyridum with 0.5m planting distance showed the best effect. The four tested species increased the soil organic matter content in varying degrees, among which the mix-planting of Pennisetum hyridum and Typha angustifolia showed the best effect. Pennisetum hyridum can increase the soil alkaline hydrolyzable nitrogen(AH-N) content, Typha angustifolia can simultaneously increase the soil available phosphorus and available potassium content. In addition, the four tested species showed varying degrees of amelioration effects on physical properties. The Pennisetum hyridum shows the best amelioration effect, followed by Sorghum bicolor × Sorghum sudanense. In summary, it is feasible to use plants to solidify and ameliorate silt soft soil, which is beneficial to realize the resource utilization of dredged soil, especially suitable for agricultural land use.

1. Introduction
At present, the total amount of dredged soil produced by the dredging of waterways in China is constantly increasing every year, even reaching billions of cubic meters. The traditional treatment method is to directly dispose to the designated water area or storage area, which is easy to cause pollution to the surrounding environment. If it is utilized as a resource, it can not only reduce the impact on the environment, but also save a lot of land resources for storage, and realize the unity of environmental benefits and economic benefits, which is the main development direction of dredged soil treatment in the future [1].
Dredged soil is a typical kind of silty soft soil. Generally, the sediment of rivers and lakes is mainly composed of fine-grained secondary clay minerals. These clay minerals have large specific surface area and adsorption capacity, having strong binding force with water\(^2\). As a result, the water content of newly dredged soil is difficult to dehydrate naturally\(^3\). Therefore, most of the dredged soil has significant fluidity, low mechanical strength and poor engineering properties \(^4\), which is difficult to be directly utilized as resources. Thus, it needs to be dehydrated and solidified by physical or chemical methods before utilization \(^5\).

At present, the regular methods of dehydrating and solidifying for dredged soil include physical mechanical method, chemical flocculation method and electroosmotic method\(^6\). The physical mechanical method is to remove the water in the soil through dehydrating machinery. The commonly used machinery includes centrifugal dehydrator and plate and frame filter press. The disadvantage is that the capacity of dewatering is limited, and it is difficult to further dehydrate after the water content is reduced to 80%\(^7\). Chemical flocculation dehydration is through the neutralization of positive and negative ions, and the adsorption of polymer complex\(^8\), so that the solid matter in the mud mixing system forms flocs, making the solid and water separated. However, chemical flocculants would change the original chemical composition of soil, which has environmental risks. The electroosmotic dehydration method is to dehydrate the soil through a direct current (DC) electric field. Under the action of the DC electric field, the water in the soil will move with it, and the sludge particles will be trapped in the filter medium of the device due to the large particle size, achieving the purpose of separating sludge and water. But the energy consumption is high \(^9\).

In order to overcome the shortcomings of the existing dehydrating methods, this study aims to explore a method of using plant to solidify and ameliorate silty soft soil (such as dredged soil and municipal sludge). Previous studies have shown that the consumption of available water in soil is mainly through the absorption of plant roots, so as to effectively reduce the soil water content\(^10\). Besides, there is a significant mechanical effect between plant roots and soil. Plant roots can enhance the shear strength of soil, and improve the stability and bearing capacity of the soil \(^11\), therefore plant root is an excellent reinforcement material\(^12\). In addition, dredged soil and other silty soft soil contain a certain amount of organic matter, nitrogen, phosphorus and other nutrient elements\(^13,14\), which are suitable for plant growth. Su and others\(^15\) used the dredged soil of Guanting Reservoir as plant growth medium, found that plants grow well on the dredged soil. Moreover, plants can effectively improve the fertility of dredged soil\(^16\).

At present, few people have conducted relevant research about the ecological solidification and melioration on silty soft soil by plants. In this study, *Pennisetum hydridum*, *Sorghum bicolor × Sorghum sudanense*, *Typha angustifolia*, and *Zea mays* were selected as the experiment objects, using the sediment of the fish pond as the planting substrate, analyzing the solidifying and meliorating effect of different plant species, to explore a method of using plants to solidify and meliorate silt soft soil.

2. Overview of the experiment site

2.1. Basic information of the experiment site

The experiment site is located on the east bank of Wabu lake in Anhui Province, with an area of 2912.8 m\(^2\), which was originally a fish pond, and was used as the experiment site after pumping (shown in Figure 1). A catchpit was set in the experiment site and equipped with drainage pump. Each experiment plot is separated by a drainage ditch (as shown in Figure 2). The thickness of sediment is about 0.5 m.
Figure 1. The experiment site before using

2.2. Soil properties of the sediment
The main physical and chemical properties of the sediment before the experiment are shown in Table 1 and Table 2, indicating that the soil type is silty clay, the plasticity index is 18.7, the water content is 60.8%, the bulk density is 1.51 g/cm², the pH of the soil is 7.67. The contents of alkaline hydrolyzable nitrogen, available phosphorus and organic matter are 230.8 mg/kg, 5.2 mg/kg and 5.07 mg/kg respectively.

| Soil classification | Moisture content (%) | Plasticity index | Bulk density (g cm⁻³) |
|---------------------|----------------------|------------------|----------------------|
| Silty clay          | 60.8                 | 18.7             | 1.51                 |

Table 2. The chemical properties of the soil before planting

| pH | alkaline hydrolyzable nitrogen (mg kg⁻¹) | Available phosphorus (mg kg⁻¹) | Organic matter (mg kg⁻¹) |
|----|-----------------------------------------|-------------------------------|--------------------------|
| 7.67 | 230.8                                   | 5.2                           | 5.07                     |

3 Experiment scheme

3.1. Experiment design
The planting date of the plant is June 1, 2020. The tested plants were Pennisetum hydridum, Sorghum bicolor × Sorghum sudanense, Typha angustifolia, and Zea mays. The seeds of Pennisetum hydridum, Sorghum bicolor × Sorghum sudanense, Typha angustifolia are provided by South China Agricultural University. The Zea mays seed brand is Jidan 7, which is widely planted in the local area and bred by Hefei Fengle Seed Co., Ltd.

There were 9 treatments, 1 blank control (CK) and 8 plant plots(T1-T8), 3 repetitions were set for T1-T8. The plant species and planting density of each treatment were shown in Table 3. There are 25 plots in the experiment area, each plot covers an area of 112 m². The specific layout is shown in Figure 2.

| Number | Plant species                  | Planting density |
|--------|--------------------------------|------------------|
| CK     | /                              | /                |
| T1     | Typha angustifolia             | 0.2m             |
| T2     | Zea mays                      | 0.3m             |
| T3     | Pennisetum hydridum           | 0.5m             |
| T4     | Pennisetum hydridum           | 0.75m            |
| T5     | Pennisetum hydridum           | 1.0m             |
| T6     | Sorghum bicolor × Sorghum sudanense | 0.1m        |
| T7     | Sorghum bicolor × Sorghum sudanense | 2g/m²        |
| T8     | Pennisetum hydridum / Typha orientalis Presl | 0.5m/1.0m  |
3.2. Observation content

The observation contents include soil physical indexes and chemical indexes. The physical indexes include water content, bearing capacity, soil bulk density, total porosity and capillary water holding capacity. The chemical indexes include total nitrogen (TN), total phosphorus (TP), total potassium (TK), alkaline hydrolyzable nitrogen (AH-N), available phosphorus (AP), available potassium (AK) and organic matter content.

3.3. Observation methods

Each index was observed on June 8, 2020 and October 22, 2020, representing before and after experiment, respectively. All observation indexes were sampled or measured directly at 7 fixed points in each experimental plot, each point was directly below the plant root, and the average value was taken as the representative value of the plot, and then the average value of 3 repetitions was taken as the representative value of each treatment. The specific measurement method is as follows:

1. Soil water content
   Soil samples with a thickness of 50 cm on the surface were taken by a soil drill, and the water content was measured by oven drying method.

2. Soil bearing capacity
   The soil bearing capacity is measured by light dynamic cone test with a measurement depth of 30 cm. Record the number of hammers hitting, and linearly interpolate through the empirical formula for the bearing capacity of the clay foundation in (TB10018-2003).

\[
\sigma_0 = 8 \tilde{N}_{10} - 20
\]

where \(\sigma_0\) is bearing capacity of foundation (kPa); \(\tilde{N}_{10}\) is Light penetration blow count.

3. Soil nutrient and organic matter content
   The content of TN and AH-N was measured by alkali-hydrolyzed reduction diffusing method; The TP was measured by Sodium hydroxide fusion-molybdenum antimony colorimetric method; The content of available phosphorus was measured by 1/2 \(H_2SO_4\) sulfuric acid method; The total potassium content was measured by NaOH melting-flame spectrophotometer method; The content of available potassium was measured by \(NH_4OAc\) extraction-flame spectrophotometer method; The content of soil organic matter was measured by the method in (GB 9834-88).

4. Soil bulk density, total porosity and capillary water holding capacity
   Soil bulk density, capillary water holding capacity and total porosity were measured by cutting ring method.
4. Results and Analysis

4.1. Soil solidification effect

4.1.1. Effect on soil water content. The results of water content is shown in Figure 3. The results show that initial water content of each plot before the experiment is relatively close, ranging from 58.8% to 63.4%, with an average of 60.8%. After the experiment, the water content of CK is the highest, 44.5%. The water content of T1, T2 and T8 are all above 30%, and the water content of T3 ~ T7 are all below 30%. The water content of T3 is the lowest, which is 27.1%, indicating that the four species can accelerate the water loss of soil. Among them, the water absorption and solidification effect of *Pennisetum hydridum* with 0.5 m spacing is the best, followed by 0.1m spacing of *Sorghum bicolor × Sorghum sudanense*.

4.1.2. Effect on soil bearing capacity. The results of soil bearing capacity is shown in Figure 4. The soil bearing capacity before the experiment is between 9.3 kPa and 21.1 kPa, with an average of 14.4 kPa. After the experiment, the bearing capacity of T1 ~ T8 ranges from 77.3 kPa to 104.3 kPa, with an average value of 91.8 kPa, which is significantly higher than that of CK (58.8 kPa), indicating that plants have different degrees of solidification effect on silty soft soil. After the experiment, the bearing capacity of T3 is the largest, which is 104.3 kPa, followed by T6 (99.8 kPa). The results showed that the curing effect of *Pennisetum hydridum* of 0.5m spacing was the best, followed by 0.1m spacing of *Sorghum hybrid sudangrass*. According to the results of T3 and T8, the effect of mixed planting of *Pennisetum hydridum* and *Typha angustifolia* is not as good as that of single species of *Pennisetum hydridum*.

![Figure 3. Soil water content before and after experiment](image1)

![Figure 4. Soil bearing capacity before and after experiment](image2)

4.2 Effect on soil organic matter and nutrient content

The measurement results of soil nutrient content in different treatment plots are shown in Table 4 below. From the results of organic matter, the content of organic matter in T1 ~ T8 treatments increase in varying degrees compared with CK treatment, and the increase of T8 treatment was the most obvious, indicating that all the four tested species can increase the content of soil organic matter, and the mixed treatment of *Pennisetum hydridum* and *Typha orientalis Presl* has the best effect. According to the result of TN and AH-N, the TN content in T1 ~ T8 was lower than that before planting, and AH-N content in T2 ~ T7 was significantly higher than that before planting. The AH-N content in T3 was highest (420.33 mg/kg), which was 1.8 times of that before planting, indicating that *Pennisetum hydridum* with 0.5m spacing has the best effect on increasing the AH-N content. The results of TP and AP showed that TP content of T1 and T8 treatments increased, while other treatments decreased, and the AP content of T1~T8 all increased compared with that before the experiment. Among them, the content of AP in T1
treatment was the highest, which was 52.36 g/kg, indicating that planting Typha angustifolia can significantly increase the content of AP in soil. From the results of TK and AK content, the TK content of T1 ~ T8 after the experiment ranged from 17.15 to 21.71 g/kg, which had no obvious change compared with that before planting. The content of AK in T1 was higher than that before planting, which indicated that the four plants had little effect on TK content. Typha angustifolia can increase the content of AK in soil.

In summary, the tested plants can increase the content of soil organic matter in varying degrees, and the mixed planting of Pennisetum hydridum and Typha angustifolia has the best effect. Planting Pennisetum hydridum can significantly increase the AH-N content in soil, and planting Typha angustifolia can increase the AP and AK content of soil at the same time.

### Table 4. Soil organic matter and nutrient content before and after treatment

| Treatments | Organic matter | TN g kg⁻¹ | TP mg kg⁻¹ | TK g kg⁻¹ | AH-N mg kg⁻¹ | AP g kg⁻¹ | AK g kg⁻¹ |
|------------|----------------|-----------|------------|-----------|---------------|-----------|----------|
| Before experiment | 15.07±1.32 | 2.32±0.07 | 1.49±0.08 | 18.00±1.22 | 230.84±18.45 | 5.20±0.33 | 43.19±3.12 |
| T1 | 17.16±1.12 | 1.47±0.12 | 1.72±0.16 | 18.02±1.26 | 179.31±6.43 | 52.36±0.47 | 57.47±4.21 |
| T2 | 17.76±0.92 | 1.34±0.13 | 0.24±0.02 | 17.15±1.33 | 313.71±21.47 | 23.41±0.15 | 39.38±2.15 |
| T3 | 19.82±1.11 | 1.60±0.04 | 0.13±0.01 | 20.55±1.87 | 420.33±22.87 | 7.31±0.23 | 34.29±3.23 |
| T4 | 15.23±0.39 | 1.43±0.14 | 0.47±0.03 | 19.39±2.01 | 288.14±14.53 | 8.24±0.17 | 34.52±1.97 |
| T5 | 14.21±0.67 | 1.32±0.05 | 0.64±0.02 | 21.27±0.93 | 260.91±16.51 | 5.51±0.39 | 35.94±2.17 |
| T6 | 16.08±1.21 | 1.23±0.09 | 0.20±0.02 | 20.91±0.89 | 359.39±7.49 | 12.12±0.06 | 38.03±2.97 |
| T7 | 14.05±0.78 | 1.17±0.12 | 0.11±0.01 | 18.37±1.54 | 334.82±25.54 | 18.13±0.11 | 38.33±3.22 |
| T8 | 22.67±1.87 | 1.41±0.11 | 1.08±0.07 | 21.71±1.99 | 132.10±5.96 | 25.09±1.27 | 40.57±3.78 |

Note: Data in the table are mean ± standard deviation (n=7).

4.3. Effect on soil physical properties

Soil bulk density and total porosity represent the loose degree of soil. Generally, the smaller the bulk density and the larger the porosity are, the more beneficial to plant root respiration and plant growth. Capillary water holding capacity represents the water supply capacity of soil to plants, and the greater the value, representing that the more sufficient water could be supplied to plants.

The effects of different treatments on soil physical properties are shown in Table 5. The results shows that, the soil bulk density decreased by 8.7% ~ 35%, the total porosity increased by 0.58% ~ 20.53%, and the capillary water capacity increased by 10.68% ~ 71.21% compared with that before the experiment, indicating that the tested plants have the effect of meliorating on soil physical properties. In terms of soil bulk density, the effect of T4 (Pennisetum hydridum of 0.75m spacing) was the best, which decreased by 49%, followed by T6 (Sorghum bicolor × Sorghum sudanense of 0.1m spacing), which decreased by 16.62%. In terms of total porosity, the melioration effect of T5 (Pennisetum hydridum of 1 m spacing) was the best, with an increase of 20.53%, followed by T7 (Sorghum bicolor × Sorghum sudanense planted in a density of 2 g/m²), with an increase of 19.48%. In terms of capillary water holding capacity, T4 (Pennisetum hydridum of 0.75m spacing) had the best effect, increased by 71.21%, followed by T2 (Zea mays of 0.3m spacing), which increased by 67.08%.

In summary, among the tested plants, Pennisetum hydridum has the best effect on improving soil physical properties, followed by Sorghum bicolor × Sorghum sudanense.
5. Conclusion

In this study, *Pennisetum hydridum*, *Sorghum bicolor × Sorghum sudanense*, *Typha angustifolia*, and *Zea mays* were selected as the experiment objects, and the effect and feasibility of plant ecological solidification and melioration on silt soft soil were explored and studied. The main conclusions are as follows:

(1) All the four tested plants can accelerate the dehydrating and solidifying process of soil. Among them, *Pennisetum hydridum* of 0.5m planting spacing has the best water absorption effect on soil, followed by 0.1m planting spacing of *Sorghum bicolor × Sorghum sudanense*. In addition, the solidification effect of mixed planting of *Pennisetum hydridum* and *Typha angustifolia* was not as good as single species of *Pennisetum hydridum*.

(2) The four tested plants can increase the content of soil organic matter in varying degrees, and the mixed planting of *Pennisetum hydridum* and *Typha angustifolia* has the best effect. Planting *Pennisetum hydridum* can significantly increase the AH-N content of soil, and *Typha angustifolia* can increase the AP and AK content of soil at the same time.

(3) The four tested plants showed different degrees of melioration effect on bulk density, total porosity, and capillary water capacity of soil. *Pennisetum hydridum* shows the best melioration effect on soil physical properties, followed by *Sorghum bicolor × Sorghum sudanense*.

In conclusion, it is feasible to use plants to ecologically solidify and meliorate silty soft soil, which is beneficial for the resource utilization of dredged soil, especially suitable for agricultural landuse. This method does not require large-scale mechanical equipment or chemicals, which has low energy consumption and little impact on the environment, and it has great significance for the reuse of dredged soil.

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