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Influence of Different Soil Moisture Content on Plant Configuration for the Submerged Area of Shifosi Reservoir, China

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Abstract

To propose a reasonable configuration of plant measures and specific planning to improve the soil quality and the surrounding ecological environment of submerged area in Shifosi reservoir, we analyzed the soil moisture content and other key physical properties such as bulk density, maximum water-holding capacity, capillary water-holding capacity, field capacity and porosity of the submerged area. Soil samples were collected within 500 m scope from the auxiliary dam and tested using test methods in compliance with the national standard LY/T1215-1999. The correlation analysis showed that a highly significant correlation existed between the moisture content with other physical properties. The capillary water-holding capacity had the highest correlation with the soil water content, followed by the maximum water-holding capacity, porosity, field capacity, and bulk density. As the changes in soil moisture content may affect the variation of other physical properties, the immersion area was divided into three regions according to their soil water contents. In region 1, the moisture content was between 23.08% and 32.96%; in region 2, the moisture content was between 21.18% and 23.08%; and in region 3, the moisture content was below 19.85%. In each region, the adaptive plant measures and configurations were put forward on the basis of natural, social and economic conditions, as well as vegetation status. In region 1, the selected tree was *Salix matsudana*, shrub was *Forsythia mandshurica*, and suitable herb was *Iris lactea var. chinensis*. In region 2, the proper tree was *Fraxinus velutina*, shrub was *Amorpha fruticosa*, and herb was *Festuca arundinacea*. In region 3, the suitable tree was *Pinus tabulaeformis var. mukdensis*, shrub was *Lespedeza bicolor*, and herb was *Eleocharis yokoscensis*. The rational allocation of vegetation may prevent soil erosion, contribute to the full use of the land of the submerged area, achieve optimization of social, economic, and ecological benefits, and provide a reference for plant configuration of other reservoirs in Liaoning Province, China.

Keywords: Plant configuration; Immersion boundary; Reservoir immersion; Ecological restoration; Shifosi reservoir

Introduction

Reservoirs are an important part of flood control engineering systems. They play important roles in flood control, irrigation, power generation, water supply, shipping, and so on. However, the immersion of the reservoir often leads to the death of surrounding plants that cannot tolerate long-term flooding. Reservoir immersion refers to the elevation of backwater level after water storage is higher than the critical embedded depth of groundwater [1]. Zhu et al. [2] studied the influence, prevention, and control countermeasures of water storage on the ecological environment of Shifosi Reservoir, China and suggested that the high soil moisture content would lead to unsuitability of the local soil environment for plant root development due to the lack of oxygen and the presence of harmful substances, leading to plant poisoning and even death. Li et al. [3] evaluated the environmental problems caused by the immersion of Shifosi Reservoir using the fuzzy comprehensive evaluation method and found that the immersion around the reservoir had a negative effect on plants. Ji [4] evaluated the immersion phenomenon of Guanting Reservoir and observed that immersion may cause soil erosion, soil swamping, and soil salinization. These unfavorable conditions lead to an abnormal growth of the plant root due to its decay. Photosynthesis is required for plant growth, but the immersion in a high water level affects light penetration, thereby inhibiting the plant growth. This negative influence ultimately leads to a reduction in the number of plants and destruction of plant communities [5]. Situated in the soil with stagnant water for a long time, the plant roots suffer from a lack of oxygen needed for the processes of root respiration, which inhibits plant growth [6]. The relationship between plant root growth and the moisture content is exceedingly close, and the different moisture content affects the distribution of plant communities. The research conducted by Li et al. [7] showed that at a normal range of the moisture content, the elevation in water levels results in a greater root biomass production, leading to a more vigorous growth of the root system. Qin et al. [8] proposed that the proper selection of trees, shrubs, and herbal plants could enhance the capacity for conservation of soil strength and fertility. Furthermore, these precautionary measures lead to improved soil physical properties, reduced soil bulk density, and increased porosity and water-holding capacity. At present, there are few studies on the ecological restoration of submerged areas of reservoirs, especially those on the selection and use of suitable plants with different moisture content tolerance in the submerged area. In our examination, we studied the properties of the submerged area of the Shifosi Reservoir of Liao River, China. The immersion boundary and the study area were delineated on the basis of the variation of water content. The most suitable plants were selected and allocated to adapt to local natural and hydrological conditions.

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Materials and Methods

General description of the study area

Shifosi Reservoir is located in Shenyang of China, Shenbei New Area Huang home and Faku County Yiniupu Township, east longitude 120°26′-124°15′ and north latitude 41°8′-42°11′. The reservoir is located in the north temperate zone with a continental climate and monsoon influence. The annual average temperature is 8°C [9], whereas the temperature of the farming period ≥ 7.0°C. There are four distinctive seasons. The winter is cold and long (about 175 days), whereas the spring and autumn are short and windy. The greatest amounts of precipitation during the year are concentrated within the period of July, August and September; the average rainfall is 721.9 mm, and the average annual relative humidity is 66.3%. The soil type is mainly brown loamy soil, and the soil pH value is within the ranges from 6.5-7.5 to nearly neutral [10].

The changes in the water level of Shifosi Reservoir were within 42.56-46.32 m, and the amplitude was 4.24 m in 2014, as illustrated in Figure 1. Water release and dredging are conducted in late April each year to purify the water and improve its quality. Impoundment begins in May and continues to July, when the wet season begins due to the relatively large amount of rainfall. The water level gradually reaches 46.2 m, which is then maintained at a normal level. The construction of Shifosi Reservoir has brought a considerable degree of influence on the farmland and woodland in the region. In some areas of the reservoir, due to the low terrain, the phenomenon of immersion occurs, resulting in higher soil moisture content. At present, the trees and shrubs grown around the reservoir include mainly *Populus*, *Salix*, and *Robinia pseudoacacia*. In addition, some plants including *Ligustrum obtusifolium*, *Leptodermis spp.*, *Cornus alba L.*, *Pinus* and *Betula platyphylla Suk.* are also widely distributed around the reservoir. Since there is no full consideration of the ecological habits of plants and reasonable collocation of different species in the introduction and selection of exotic species, some plants cannot adapt well to the local environment. For example, *Robinia pseudoacacia* may easily suffer from root rotting, spike topping, even death when grown in the area with high moisture content. *Leptodermis spp.* may subject to diseases and insect pests, even death due to waterlog.

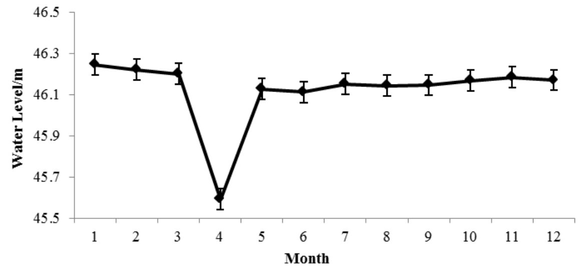

Figure 1: Water level variations of Shifosi Reservoir in 2014.

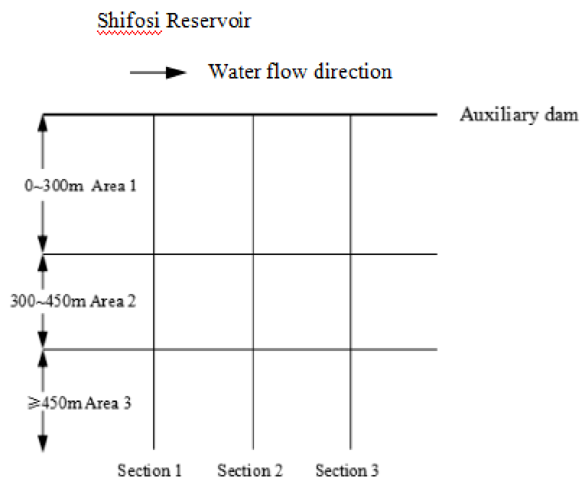

Figure 2: Experimental design.

Experimental design

Since farming activities affect the physical properties of the soil, soil samples from the submerged area of Shifosi Reservoir were collected at three time points: before the period of farming (in April 2015), during the farming period (in May), and after the farming period (in June). The experimental design is presented in Figure 2. Three sections in Chen Ping Hamlet were selected for the study, which are perpendicular to the auxiliary dam of Shifosi Reservoir. Marking a point every 50 m along the section, 10 points were established in each section, or a total of 30 observation points in the three sections were employed in the investigation. Then, the soil moisture content was determined using over-drying method in the laboratory. Each of the sections was divided into three regions according to the changing characteristics of the soil moisture content. The distances between the three regions and the auxiliary dam were as follows: zone 1, 0-300; zone 2, 300-450; and zone 3, more than 450 m. A soil profile was dug up at each sampling point at soil layers of 0-10, 10-20, and 20-30 cm depth. Samples were collected at each soil layer with a ring cutter whose volume was 100 cm^3 (a diameter of 5 cm and a height of 5 cm). Soil samples were taken in triplicate and placed into polyethylene plastic bags. Then, the pit was backfilled and marked to use its location as a reference for the next sampling. The samples were transported to the laboratory for analysis.

Testing methods based on the National Standard LY/T1215-1999 were employed. The parameters tested involved the moisture content, bulk density, maximum water-holding capacity, capillary water-holding capacity, field capacity, and porosity. The calculations and statistical analysis of the test data were conducted with Microsoft EXCEL and SPSS16.0.

Results and Analysis

Analysis of the correlation between the moisture content and other physical properties

The moisture content in the submerged area of a reservoir varies with the distance to the auxiliary dam. The changes in the moisture content lead to variations in other soil physical properties. As can be seen from Table 1 showing the correlation between the moisture content and other physical parameters, there was a highly significant correlation between the moisture content and bulk density, maximum water-holding capacity, capillary water-holding capacity, field capacity, and porosity. The results indicated that the changes in the moisture content affected the variations in the other physical properties with a significant negative correlation with the bulk density. The changes in the moisture content had a greater effect on the capillary water-holding capacity, which was indicated by the relatively larger correlation coefficient between the moisture content and the capillary water-holding capacity. In contrast, the changes in the moisture content had a minor effect on the bulk density as evidenced by the comparatively

Items	Bulk density	Maximum water	Capillary water	Field capacity	Total porosity
Soil water content	-0.441**	0.723**	0.785**	0.619**	0.698**

Note: **represents a significant correlation at P=0.01.

Table 1: Correlation between soil water content and other soil physical properties.

Physical properties	0-300 m	300-450 m	≥ 450 m
Soil water content (%)	32.96	22.18	19.85
Bulk density ($g·cm^{-3}$)	1.26	1.38	1.37
Maximum water (%)	36.90	30.95	30.62
Capillary water (%)	34.35	29.08	27.48
Field capacity (%)	23.54	20.98	20.95
Porosity (%)	46.40	41.13	41.63

Note: 1. The above data were obtained from April to June of 2015; 2. The average values of water content, bulk density, water-holding capacity, and total porosity of the 0-30 cm soil layers were measured from April to June 2015.

Table 2: Soil physical properties at different distances from the auxiliary dam.

low value of the correlation coefficient between the moisture content and the bulk density. Soil physical properties are an important index used to determine the current condition of soils [8]. Since an extremely significant correlation exists between the moisture content and other soil physical indicators, the moisture content can be used as a basis for the selection of plants for growing in the submerged area.

Analysis of soil physical properties in the submerged area

Soil physical properties play an important role in the growth of plants [11]. In our study, soil samples were collected in different regions of the submerged area, and their physical properties were determined (results are shown in Table 2). As can be seen from the figure, the soil moisture content, water-holding capacity, and porosity decreased with the increase of the distance from the auxiliary dam, whereas soil bulk density was augmented. Soil moisture content is the most important factor in the selection of suitable plants, whereas bulk density reflects the situation of soil compaction. In addition, soil water-holding capacity shows the ability of the soil to hold water, and the porosity determines the levels of soil aeration, water permeability, fertilizer availability, and other properties. Usually, the soil is moist when the moisture content is more than 20%. Normal plant growth occurs at bulk density values between 1.25 $g•cm^{-3}$ and 1.40 $g•cm^{-3}$, and porosity in the range 45%-56%. In the studied submerged area, the moisture content was more than 20% in the range of 450 m from the auxiliary dam, so the soil was considered moist. The soil bulk density in this region was less than 1.40 $g•cm^{-3}$, and was thus suitable for plant growth. However, the average value of the porosity was only 43.05%, which is slightly lower than 45%. Thus, deep plowing had to be done before conducting the plant configuration to loosen the soil and improve the soil porosity.

Determination of the boundaries of the submerged area

As can be seen from Figure 3, with increasing the distance from the auxiliary dam, the soil moisture content became lower, showing a gradual downward trend. The moisture content of each month at a distance of 450 m from the auxiliary dam was nearly consistent. The moisture content at a distance of 500 m from the auxiliary dam was not changed, which indicates that the distance of 450 m from the auxiliary dam is the immersion boundary reached.

Plants configuration scheme of the submerged area

Generally, the dominant species, which are most suitable for the local natural environment, should be selected for the design of plants configuration. They should be wet and barren-resistant, with adequate survival, acceptable soil reinforcement capability, and characterized by low costs for management and maintenance. Since the soil moisture content decreased with increasing the distance from the auxiliary dam, to make the selected vegetation measures more pertinently, the mode of plants configuration in the submerged area was divided into three regions. The moisture content of region 1 was between 23.08% and 32.96%, and thus mainly water-resistant plants had to be selected. Therefore, the most suitable tree species was *Salix matsudana*, whereas *Forsythia mandshurica* was the most suitable shrub and *Iris lactea var. chinensis* the most appropriate herb. The moisture content of region 2 was between 21.18% and 23.08%, which was suitable for the growth of moisture-resistant plants. Thus, the proper tree was *Fraxinus velutina*, the shrub was *Amorpha fruticosa*, and the herb was *Festuca arundinacea*. The soil moisture content of region 3 was lower than 19.85%, and thus plants of soil and water conservation and evergreen were appropriate. To compensate for the landscape deficiency of submerged area in winter, some evergreen plants were properly allocated. The most suitable tree species was *Pinus tabulaeformis var. mukdensis*, the shrub *Lespedeza bicolor*, and the herb *Eleocharis yokoscensis*. Meanwhile, to achieve better ecological and landscape benefits, the plants selected above had to be allocated according to the optimal configuration of trees, shrubs, grass, and the soil area. That is, a tree, six shrubs and 20 m^2 of herbaceous plants may be planted on a land area of 29 m^2 [12].

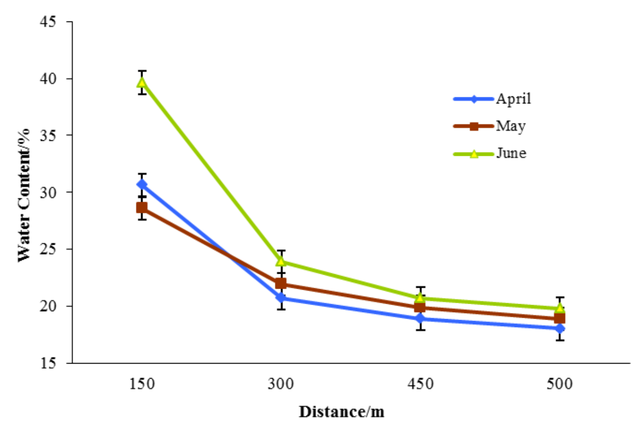

Figure 3: Moisture content variations at different distances from the auxiliary dam.

Conclusion and Discussion

The results of analysis of the variance of soil physical properties in the submerged area of Shifosi Reservoir indicated that the soil moisture content is highly significantly correlated with the bulk density, maximum water-holding capacity, capillary water-holding capacity, field capacity, and porosity of the soil studied. Among these parameters, there was a significant negative correlation between the bulk density and the moisture content, which is consistent with the results obtained by Wang et al. [13] from the study of the soil physical properties in the water conservation forest of Huangqian Reservoir.

In the tests we conducted, the submerged area of the reservoir was divided into three regions according to the soil physical characteristics. The plants selected for growing in region 1 were classified as water-resistant based on the principles of plant selection and construction. The most suitable tree, shrub, and herb were *Salix matsudana*, *Forsythia mandshurica*, and *Iris lactea var. chinensis*, respectively. Zhang et al. [14] and Zhao [15]. separately pointed out in their studies that *Salix matsudana* had the highest survival rate, and *Forsythia mandshurica* had not only a high survival rate but also low maintenance costs and was attacked by fewer plant diseases and insect pests under identical immersion conditions. It is noteworthy that *Iris lactea var. chinensis* had pronounced vitality, strong soil and water conservation abilities, and potential for soil improvement, thus it was called the pioneer of ground cover plants. Therefore, *Salix matsudana*, *Forsythia mandshurica*, and *Iris lactea var. chinensis* are more suitable for the immersion area. The plants in region 2 were mainly moisture-resistant, and thus the most proper tree species with high waterlogging tolerance was *Fraxinus velutina*, for which Chen et al. [16] obtained a survival rate of 95% in Shenyang. Therefore, it is worth popularizing as a greening tree species. The most suitable shrub for this region was *Amorpha fruticosa*. In previous studies, Wang et al. [13] concluded that *Amorpha fruticosa* had a high survival rate under different waterlogging stress. We found that the most suitable herb for region 2 was *Festuca arundinacea*, which is consistent with findings of previous related research [17] that *Festuca arundinacea* had strong waterlogging tolerance and a high survival rate in flooding conditions. The appropriate plants in region 3 were characterized by soil and water conservation and evergreen. The most suitable tree for this region was *Pinus tabulaeformis var. mukdensis*, shrub was *Lespedeza bicolor*, and herb was *Eleocharis yokoscensis*. *Pinus tabulaeformis var. mukdensis* is a native species in Shenyang that can contribute to the beauty of the landscape in the Northeast in winter [18]. Importantly, *Lespedeza bicolor* can effectively prevent soil erosion and bring a certain economic value [19]. *Eleocharis yokoscensis* is widely distributed in Liaoning and is a preferred species used for soil and water protection.

n this paper, we describe our experiments conducted to study the changing regularities of soil moisture contents and soil physical properties of the submerged area in Shifosi reservoir. Based on the soil physical properties in different submerged areas around the Shifosi Reservoir, plant measures were configured scientifically and reasonably, which would greatly improve the ecological environment of the submerged area, effectively prevent soil deterioration, contribute to the full use of the land of the submerged area, and maximize the social, economic, and ecological benefits of the immersion area.

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