

Effects of Soil on Degradation of *Robinia pseudoacacia* Forests in the Yellow River Delta in China

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Abstract

Soil quality has significant importance for the growth and sustainability of plants. However, due to the variability and diversity of soil characteristics, many trees suffered death according to their confrontation degree. Over the past several decades, *Robinia pseudoacacia* forests in the Yellow River delta of China, lose health and died without an obvious cause. This study focuses on evaluating the role of soil characteristics (moisture content, soil salinity content, soil bulk density, soil texture (the percentages of soil sand, soil silt, and soil clay) and pH value on the deterioration of health level of *Robinia pseudoacacia* forests in the area. To do so, three health levels such as healthy, medium dieback, and severe dieback forest were firstly classified based on the United States Department of Agriculture Forestry Bureau of crown condition classification guide and in situ survey, then soil properties in vertical direction were analyzed by five sampling points for each forest type from surface to the depth of 260 cm with eight layers (0-20 cm, 20-40 cm, 40-60 cm, 60-100 cm, 100-140 cm, 140-180 cm, 180-220 cm and 220-260 cm) for healthy and moderate dieback and 0- 220 cm depth with seven layers for severe dieback because the water occurred after 220 cm depth. The results indicated that there are significant differences in soil moisture content and soil conductivity among three forest health conditions. For a vertical change of soil characteristics only soil particle sizes (sand, silt and clay) had a significant difference in three forest health conditions. For system roots, absorptive roots were observed down to 230 cm depth for healthy *Robinia pseudoacacia* forest but moderate and severe dieback *Robinia pseudoacacia* forests, roots are found in the surface layer.

Keywords: Soil characteristics; Forest health conditions; Tree dieback; *Robinia pseudoacacia* forest; Yellow river delta

Introduction

The plant cannot grow in poor soil. Soil conditions had a strong influence on plant growth [1]. The structure of soil, lays a significant role in plant growth [2] thus well development, bad development or decay of the plant. Soil moisture is one of the most important abiotic factors determining vegetation growth, variability and regeneration [3] but it has a significant impact on growth and productivity of some plants through overcoming of the water stress condition [4] it affects the potential growth of some plants species [5]. Plants growing in well-aerated soils are less stressed by drought or excess water [6]. Lower bulk density is normally optimal soil conditions for many plants and ensures a high crop productivity [7]. Soil salinity declines the growth rates of the plant [8] and its extreme levels can cause plant death [9]. This problem of salinity has strongly affected Yellow River Delta [10,11] and there is no significant difference in soil salt content among different land-use types in the region [11] but high salinity generally appeared in the topsoil [12]. The salinity becomes a threat to many tree species to survive.

R. pseudoacacia is one of the forest species grown in the Yellow River Delta and has been widely planted in the middle of 1980's, but the dieback or dead of *Robinia Pseudoacacia* had been noted in some areas of Yellow River Delta in the early 1990's [13,14]. However, *Robinia pseudoacacia* have a certain resistance to the condition of salt [15], but the plant grows better under conditions of low salinity [15].

Within different studies, the dieback or dead *Robinia Pseudoacacia* plantation were detected through the analysis of different health levels [13,14], three health level classes that are healthy, medium dieback, and severe dieback with 41.46%, 36.09%, and 22.45% respectively observed based on tree crown symptoms within the case study [16].

Robina pseudoacacia is able to grow in a variety of soil conditions [17] and it has the ability to vary its growth patterns, thrive in many regions, and grow at very aggressive rates [18], but in the dry condition,

it is not easy to adapt [14,19] because the plant need soil water to improve photosynthetic capacity and biomass accumulation [20]. Moreover, *Robinia pseudoacacia* avoids compact soils and those that are waterlogged for long periods of time [17]. Thus, the plant seems to be limited by water supply. *Robinia pseudoacacia* can grow almost in any soil acid or alkaline except that which is permanently wet [21].

The goal of this paper is to explore the cause of dieback or dead *Robinia pseudoacacia* forest plantation of Gudao forestry area in the Yellow River Delta, China, to provide effective management and protection measurement.

Study area

The study was undertaken in the Yellow River Delta located in Dongying City, Shandong Province of East China with 36°55'N-38°16'N, 117°30'E-119°20' E with approximately 5400 Km² of total area [16].

The Yellow River Delta belongs to the temperate continental monsoon climate and has four distinct seasons such as hot and humid summer and a cold and dry winter.

The area is topographically flat with a gentle slope. It is high in the south and west, low in the north and east. The highest elevation is 28

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m in the southwest and the lowest is 1 m in the northeast. The natural gradient is 1/8000-1/12000 [22].

The main soil types in this area are calcaric fluvisols, salic fluvisols, and gleyic solonchaks, under which *Robinia pseudoacacia* is able to growth [17]. According to Ref. [23], three main factors were found to be the cause of dieback of *Robinia pseudoacacia* trees in this study area: soil texture, soil salt content, and ground water levels.

The area has 393 plant species and varieties in the region; most of them are salt-tolerant [24] such as *Tamarix chinensis*, *Suaeda salsa*, *Salicornia europaea* [25]. Artificial *Robinia pseudoacacia* forest is among them and is planted in Gudao, Junmachang, Abandoned yellow river and Natural reserve (Figure 1). Sampling points locate in Gudao forest area, the majority of trees having more than 25 years old.

Methods

Classification of health conditions of *Robinia pseudoacacia* forests

Health conditions of *Robinia pseudoacacia* forests were classified into three levels: level 3 for healthy or slight dieback, level 2 for moderate dieback and level 1 for severe dieback or death according to the United States Department of Agriculture Forestry Bureau of crown condition classification guide [26] through five trees vigor index (leaf transmittance, crown width, crown density, mortality, live crown ratio) and are reported in Table 1.

Field investigation and sampling procedure

Three types of the health status of *Robinia pseudoacacia* were studied, and for each type, five sample points were randomly collected along the vertical direction of the river because more serious dieback was observed more close to the river and along the river direction [16].

From April 25-29, 2015, soil samples were collected in the soil samples at various depth intervals: 0-20 cm, 20-40 cm, 40-60 cm, 60-100 cm, 100-140 cm, 140-180 cm, 180-220 cm and 220-260 cm for each sampling point but sample for the severe dieback forest soil, were collected up to 180-220 cm because groundwater occurs after the 220 cm depth, and the distribution of absorptive roots (diameter less than 2 mm) were observed and measured during soil sampling periods. We dug a rectangle hole of 80 cm of small side and 1.5 m of large side and 230 cm of deep. In sample collection, soil samples were taken on the side for seven layers and for the last one soil sample was taken at the bottom.

Soil properties analysis

Soil properties analysis included soil moisture content, soil salinity, soil texture, soil bulk density and pH value. The soil salinity content was determined by soil electrical conductivity. Electrical conductivity is the common method in soil salinity measuring [27], by using TOLEDO Seven2GOTM METTLER with measurement of 1:5 in the soil solution. Soil moisture content was determined by the difference of the soil weight before drying and after drying per dry weight [28]. The soil bulk density was calculated by the ratio of dry weight and volume of ring knife.

According to United States Department of Agriculture [29] on soil textural classification, sand, silt and clay particle size was classified through calculation of the percentage of their particles size. The percentage content of each particle size was obtained by using the LS13320 laser particle size analyzer.

Recorded data were analyzed by using Microsoft excel 2013 and IBM SPSS Statistics v22 software. SPSS software has been used to analyze soil

characteristics among forest condition levels and different sampling layers with ANOVA method and calculate the correlation coefficient of forest condition and soil characteristics by the method of Pearson correlation analysis. The comparison of soil characteristics and sampling depth made to analyze the change in three levels of forest status. Normalization was used to analyze the vertical variation of soil characteristics in the different health condition of *Robinia pseudoacacia* forest.

Results

Soil characteristics among different forest health conditions

The soil characteristics of the study area (soil bulk density, soil moisture content, soil salinity content, pH value, silt, sand, and clay) were analyzed by three forest health levels. The result (Table 2) showed that there are significant differences in soil moisture content and soil conductivity among three forest health conditions. Other soil characteristics (sol bulk density, sand, silt, clay, and pH value) did not show significant differences between the three forest health statuses.

According to Pearson correlation analysis, positive and negative correlations were observed (Table 3). *Robinia pseudoacacia* health condition showed the significant correlation relationship positively with the soil sand content and negatively correlated with soil moisture content, the soil salinity content, clay, soil bulk density, and silt but *Robinia pseudoacacia* health condition had no significant correlation with pH value. The good health condition of *Robinia pseudoacacia* is

Indicator	Level 3	Level 2	Level 1
Live crown ratio	>90%	70%-85	50%-65%
Crown density	>80%	50%-70%	20%-40%
Crown diameter	>55%	26%-54%	1%-25%
Dieback	0%-5%	10%-25%	>30%
Foliar transparency	0%-20%	30%-50	>60%

Table 1: The CCCG a tree vigor indicators and classification thresholds a CCCG: Crown Condition Classification Guide; b Values of 100% were recorded as 99%, and intermediate values were upgraded to the next full 5% grouping.

	SMC	SBD	Sand	Silt	Clay	SC	pH value
H	6.25 ^a	1.34	50.16	47.13	2.71	0.06 ^a	8.06
M	17.75 ^b	1.35	49.15	47.58	3.27	0.13 ^b	7.99
S	26.72 ^b	1.23	29.34	54.28	3.88	0.16 ^b	7.04

Table 2: Two ways-ANOVA on soil characteristics among three forest condition of *Robinia pseudoacacia* (H=Healthy forest, M=Medium dieback forest, and S=Severe dieback forest). SMC: Soil moisture content (%), SBD: Soil bulk density (g/cm³), SC: Soil conductivity (us/cm), soil texture: the percentage of soil sand, silt and clay content and pH value a: p<0.05, b: p<0.01.

	Forest condition	SMC	SBD	Sand	Silt	Clay	SC	pH value
Forest condition	1							
SMC	-0.900**	1						
SBD	-0.386**	0.269**	1					
Sand	0.304**	-0.304**	0.066	1				
Silt	-0.289**	0.290**	-0.076	-0.999**	1			
Clay	-0.427**	0.420**	0.071	-0.822**	0.796**	1		
SC	-0.543**	0.523**	-0.047	-0.520**	0.509**	0.568**	1	
pH value	0.002	-0.104	0.145	0.417**	-0.406**	-0.478**	-0.175	1

**Correlation is significant at the 0.01 level (2-tailed)

SMC: Soil moisture content (%), SBD: Soil bulk density (g/cm³), SC: Soil conductivity (μS/cm), Soil texture: the percentage of soil sand, silt and clay content and pH value

Table 3: *Robinia pseudoacacia* health level and soil characteristics correlation.

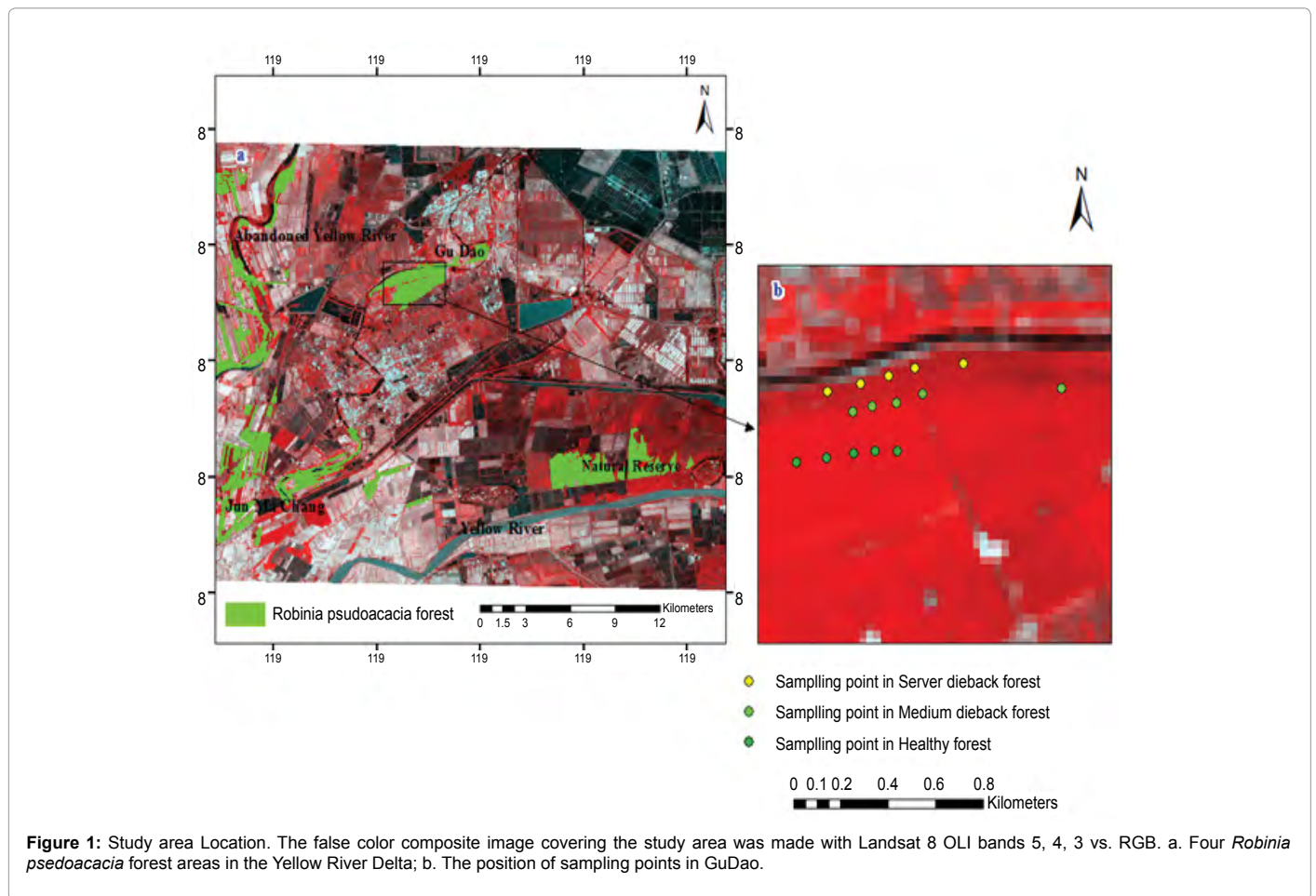


Figure 1: Study area Location. The false color composite image covering the study area was made with Landsat 8 OLI bands 5, 4, 3 vs. RGB. a. Four *Robinia pseudoacacia* forest areas in the Yellow River Delta; b. The position of sampling points in GuDao.

seen by means of the increase of soil sand percentage but inversely associated with an increase in soil moisture content, soil salinity, soil bulk density, soil clay and silt percentages.

Vertical change of soil characteristics at different forest health conditions

Vertical change of soil characteristics included soil bulk density, soil moisture content, soil salinity content, pH value, silt, sand, and clay were analyzed among three forest health levels by one-way ANOVA. The result shows only soil particle sizes (sand, silt, and clay) had a significant difference in three forest health conditions. Soil moisture content had a significant difference in healthy and severe dieback forestry. Soil conductivity had a significant difference in medium dieback forest and severe dieback forest. pH value had a significant difference in healthy and medium dieback forest (Table 4).

The results (Figure 2) showed soil characteristics variation at different sampling depth. Percentage of soil sand had uptrend presenting significant increase with increasing in sampling depths while percentage of soil silt and soil clay show downtrend which present significant decrease at a significance level of 0.05. Soil bulk density with fluctuation trend shows no significant difference among three forest health conditions. At healthy forest, soil moisture content is significantly high on surface layer because the soil directly accepts the rainfall supply, coupled with the surface litter and understory grass

Soil properties	Health forest		Medium dieback		Severe dieback	
	F	Sig.	F	Sig.	F	Sig.
SMC	36.698	0.000	3.133	0.012	4.716	0.002
SBD	1.311	0.277	1.533	0.192	3.695	0.008
Sand	15.627	0.000	59.803	0.000	33.451	0.000
Silt	15.397	0.000	61.284	0.000	29.881	0.000
Clay	13.825	0.000	15.011	0.000	34.588	0.000
SC	1.171	0.347	2.312	0.050	2.228	0.000
pH value	7.945	0.000	6.369	0.000	4.575	0.071

Significance level: 0.05

SMC: Soil moisture content (%), SBD: Soil bulk density (g/cm³), SC: Soil conductivity (μS/cm), Soil texture: the percentage of soil sand, silt and clay content and pH value

Table 4: One-way ANOVA test on soil properties at different sampling depths on the three health levels of *Robinia pseudoacacia* forest stands.

root barrier, soil moisture decreases continuously but in the middle layer, soil moisture content were lower and seems to reach the valley due to the surface soil gravity water which leads to the formation of dry layer in the middle; at severe dieback forestry, soil moisture content significantly increased with increasing in sampling depths due to groundwater recharge and to its location near and along the river through the continuity of river flows.

It is also observed from (Figure 2) that high salinity generally appeared in the topsoil (0-20 cm) at healthy forestry or sub-topsoil (20-40 cm) at severe dieback forestry.

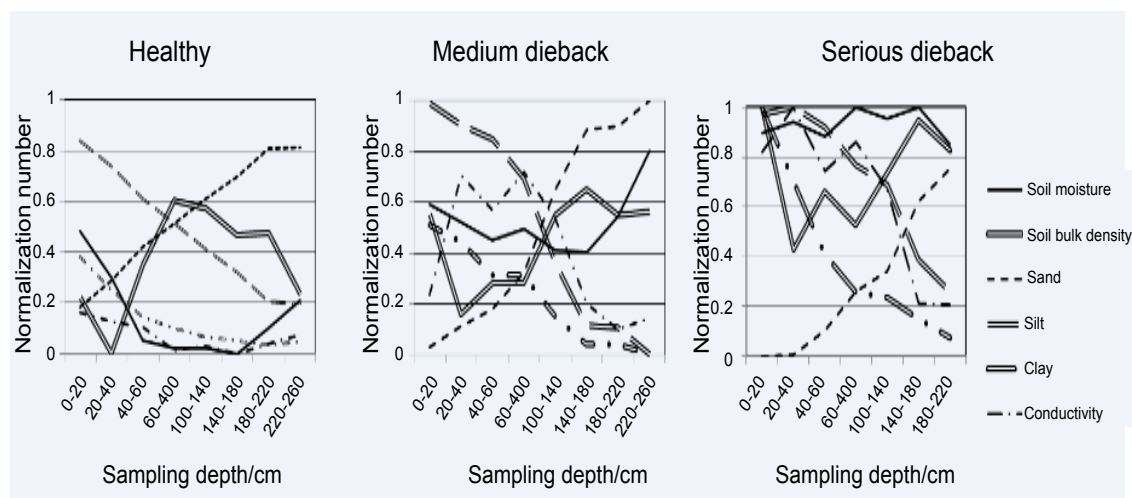


Figure 2: Vertical variations of soil properties at three health levels of *Robinia pseudoacacia* forests.

The distribution of absorptive roots in different forest health conditions

The root system is a major part of the plant. Roots offer the significant advantages of fundamental processes in plant development, they are involved in the acquisition of water and nutrients, synthesis of plant hormones, and storage functions [30].

In this study, the healthy forest of *Robinia pseudoacacia* is characterized by the deep root system, absorptive roots were observed down to 230 cm depth but for moderate and severe dieback *Robinia pseudoacacia* forests, roots are not deepened. Their absorptive roots were found in less than 60 cm deep due to sticky and light gray soil layer that is near 40 cm deep and little roots passing through but little roots tried to deep to 120-180 cm depth and most of them showed edema like, and were fostered by touch. In addition, the moderate and severe dieback *Robinia pseudoacacia* forests present much clay soil in the surface layers that alter the normal deeper growth of *Robinia pseudoacacia* roots.

Discussion

The soil moisture rates in *Robinia pseudoacacia* forest varied periodically with seasons, the soil moisture rate is lower in the dry season as precipitation is rare and high evaporation but higher in the rainy season [29,30]. In this study, samples were taken in dry season and the soil moisture decreased with soil depth in healthy *Robinia pseudoacacia* forest because of soil water loss by transpiration of trees, understory grasses and evaporation from the ground surface [31-33], while increase in severe dieback forest because of lower groundwater table (less than 2 m at our sampling period) the reason for this phenomenon was that all severe dieback *Robinia pseudoacacia* forests located near river (less than 100 m) and also distributed along river direction (Figure 1). Moisture could limit soil respiration when the soil was too wet [34].

Our results contradict the majority of literature on forest dieback which generally considers increased forest mortality related to climatic stress from drought and high temperatures [35-37] but were not different from Ref. [38-40] results which consider forest decline and massive tree mortality to be the resulted from persistent wetness.

This study found that high salinity generally appeared in the topsoil (0-20 cm) at healthy forestry or sub-topsoil (20-40 cm) at severe dieback forestry. And it is found that the higher soil salinity content the higher deterioration degree of forest consequently inhibition of root growth [13]. [28,41] have convincingly demonstrated that soil salinity significantly affects the *Robinia pseudoacacia* forest health. However, our result compared to soil moisture and soil salt content and found that soil moisture had a strong effect on degradation of the forest.

By *in situ* survey, severe dieback forests were frequently seen near the ditch and road and along the river (Figure 3a and 3b) because forest roots soak in water and soil are wet and near the road, there might be an increase in high surface runoff thus increases moisture content. Also with micro-morphology consideration, trees are healthy in higher places than those in lower places (Figure 3c). Topography plays an important role in the spatial organization of soil moisture at different scales.

To better understand the cause of degradation of *Robinia pseudoacacia* forest, the distributions of absorptive roots were conducted because roots of most plants cannot function or even remain alive for drought condition. However, *Robinia pseudoacacia* can develop deep roots for drought resistance [42], which were also found in the healthy forest stands (absorptive roots were observed down to 230 cm depth) in our study area but many roots of severe *Robinia pseudoacacia* are located in the surface layer, the area saturated with water. Soil with high moisture content restricts rooting than those with low moisture content [43]. Periods of water saturation lead to poor aeration [6] and can cause damage to many roots due to the lack of soil aeration [43], inevitably reduce photosynthetic rates and induced carbon starvation [40]. Carbohydrate plays an important role in plant respiration and of plant growth [41,42]. Moreover, the soil layer near 40 cm deep was sticky and light gray that alter may root too deep the soil consequently, crown dieback increased [26].

Changes in bulk density affect available water and air capacity, and strongly influence permeability, drainage rate, and penetration by plant roots [44-46]. In this study, soil bulk density was high in severe dieback forest and seems to be one factor that hinders normal plant rooting and leads to the poor development and growth of the plant [47]. The bulk density can be evaluated using relative compaction. As compactness becomes greater, soil hardness becomes harder leading to

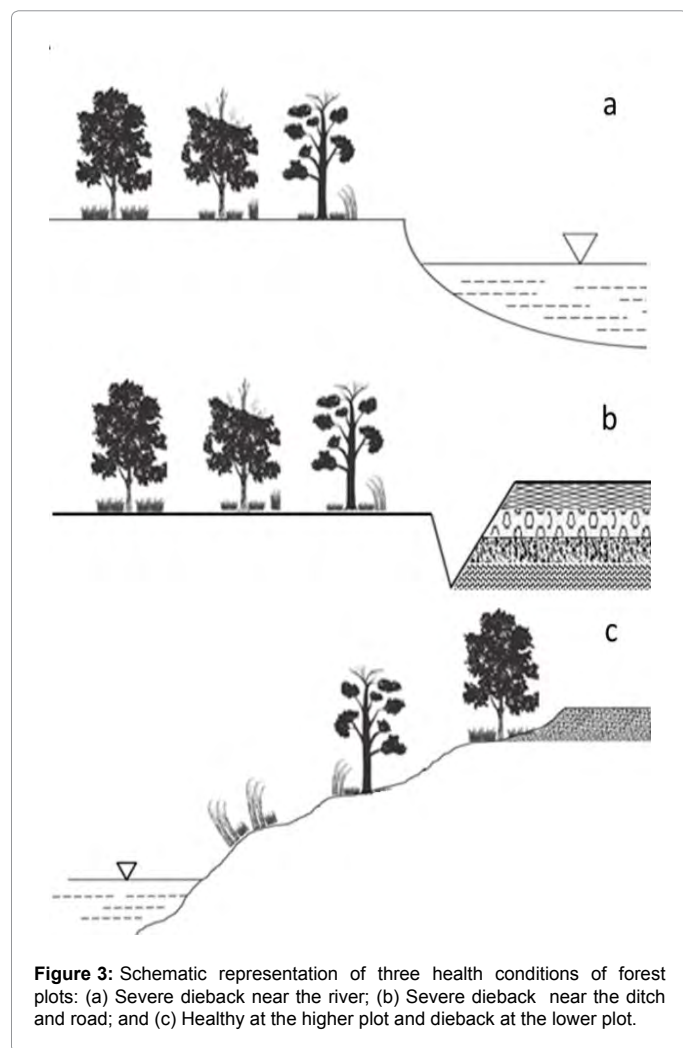


Figure 3: Schematic representation of three health conditions of forest plots: (a) Severe dieback near the river; (b) Severe dieback near the ditch and road; and (c) Healthy at the higher plot and dieback at the lower plot.

a rise in mechanical stress in plant roots interpenetrated in soil [48,49]. Moreover, soil with the high bulk had a significant higher penetration resistance than the low bulk density [50].

Conclusion

The study of the cause of *Robinia pseudoacacia* dieback in Yellow river delta especially in Gudao forest as an area of focus through analysis of soil characteristics in different soil depth, showed that the main reason for the significant decrease in trees health level from the healthy to severe dieback *Robinia pseudoacacia* forest were soil moisture content and soil conductivity. However, soil moisture and soil salinity show a higher correlation with soil texture and soil bulk density. Also, it was found that topography had a great influence on health conditions of *Robinia pseudoacacia* forest. The future research should be done on plants well grown in saturated soil and high salinity that can be grown with *Robinia pseudoacacia* because the soil respiration varies due to the vegetation type [51] or should look to the way *Robinia pseudoacacia* be moved in high places, as well as away from the river and road. Ref [53]'s study surveyed soils near and within 3, 9, and 19-year-old plantations of poplar (*Populus simonii*) in the central part of Naiman Country, eastern Inner Mongolia, China and found that there are changes in the soil properties following afforestation including the accumulation of fine particles (clay and silt), soil moisture level, amounts of available

N and available P and soil organic carbon in the surface horizons and increased slowly in the first 9 years period and then rapidly between 10 and 19 years [52] thus the same measure is suggested for our case study.

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Author Contributions

Hong Wang proposed the idea of the topic and organized the writing. Claire Dusabemariya contributed to laboratory analysis and organization of the writing. Zhao Y, Song Y, Kaiyu L and Zhong Y contributed to laboratory analysis and the field survey data.

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