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

Hong W*, Claire D*, Yu Z, Yin S, Yu L and Yi Z  
School of Earth Sciences and Engineering, Hohai University, No. 1 Xikang Road, Nanjing 210098, China

**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 [13,14], three health level classes that are 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.

*Corresponding authors: Hong W, School of Earth Sciences and Engineering, Hohai University, No. 1 Xikang Road, Nanjing 210098, China, Tel: +86 025 83787234; E-mail: hongwang@hhu.edu.cn  
Claire D, School of Earth Sciences and Engineering, Hohai University, No. 1 Xikang Road, Nanjing 210098, China, Tel: +8613601588348; E-mail: sabedeclaire@yahoo.fr  
Received May 24, 2016; Accepted June 17, 2016; Published June 24, 2016

**Citation:** Hong W, Claire D, Yu Z, Yin S, Yu L, et al. (2016) Effects of Soil on Degradation of *Robinia pseudoacacia* Forests in the Yellow River Delta in China. Forest Res 5: 182. doi:10.4172/2168-9776.1000182

**Copyright:** © 2016 Hong W, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
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 calcareous fluvisols, salic fluvisols, and gleicy solonchaks, under which Robinia pseudoacacia is able to grow [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 Guadu, Junmaching, Abandoned yellow river and Natural reserve (Figure 1). Sampling points locate in Guadu 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 foil 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 (soil 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% |
| Foliage transparence | 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.

| Forest condition | SMC | SBD | Sand | Silt | Clay | SC | pH value |
|------------------|-----|-----|------|------|------|----|---------|
| Healthy forest | 6.25± | 1.34 | 50.16 | 47.13 | 2.71 | 0.06± | 8.06 |
| Medium dieback | 17.75± | 1.35 | 49.15 | 47.58 | 3.27 | 0.13± | 7.99 |
| Severe dieback | 26.72± | 1.23 | 29.34 | 54.28 | 3.88 | 0.16± | 7.04 |

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

| Forest condition | SMC | SBD | Sand | Silt | Clay | SC | pH value |
|------------------|-----|-----|------|------|------|----|---------|
| Healthy forest | 0.002 | -0.104 | 0.145 | 0.417 | -0.506 | -0.478 | -0.175 |
| Medium dieback | 0.523 | -0.047 | 0.520 | 0.509 | 0.568 | 1 |
| Severe dieback | 0.543 | -0.076 | 0.982 | 0.796 | 1 |

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

**Acknowledgements**

The research was supported by the National Science Foundation of China (41471419 and 40871230) and the State Key Laboratory of Resources and Environmental Information System.

**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.

**References**

1. Lu TO (2005) Effects of Some Soil Properties on the Growth of Hybrid Poplar in the Terme-Göldir: Region of Turke. Turk J Agric 29: 221-226.
2. Passiourea JB (1991) Soil Structure and Plant Growth. Aust J Soil Res 29: 717-728.
3. Wang S, Fu BJ, Gao GJ, Yao XL, Zhou J (2012) Soil moisture and evapotranspiration of different land cover types in the Loess Plateau, China. Hydrol Earth Syst Sci, pp: 2883-2892.
4. Anju SV, Koppa AG (2013) Influence of in situ soil moisture conservation measures on growth and productivity of Acacia auriculiformis. Karnataka J Agric Sci 26: 170-171.
5. Aslanidou N, Smiris M (2001) Distribution of soil moisture content and its effect on the potential growth of the overstory species in North-East Chalkidiki. Silva Gandav 88: 40-56.
6. Bot A, Benites J (2005) The importance of soil organic matter.
7. Khan B, Abilmit A, Mahmood R, Qasim M (2010) Robinia pseudoacacia leaves improve soil physical and chemical properties. Journal And L 2: 266-271.
8. Bennett DL (1995) Using the EM38 to measure the effect of soil salinity on Eucalyptus globulus in south-western Australia. Agric Water Manag 27: 69-86.
9. Imbert D, Dulormme M (2015) Impact patterns of soil salinity variations on the survival rate, growth performances, and physiology of Pterocarpus officinalis seedlings. Trees 29: 119-128.
10. Weng YL, Gong P, Zhu ZL (2010) A Spectral Index for Estimating Soil Salinity in the Yellow River Delta Region of China Using EO-1 Hyperion Data. Pedosphere 20: 370-388.
11. Fang H, Liu G, Kearney M (2005) Georelational Analysis of Soil Type, Soil Salt Content, Landform, and Land Use in the Yellow River Delta, China. Environ Manage 35: 72-83.
12. Yu J, Li Y, Han G, Zhou D, Fu Y, et al. (2014) The spatial distribution characteristics of soil salinity in coastal zone of the Yellow River Delta. Environ Earth Sci 72: 589-599.
13. Yao L, Fei L, Gui S, Liu Q, Liu G (2008) Remote sensing for monitoring on the health of artificial Robinia Pseudacacia Forests in the Yellow River Delta. Natl Nat Sci Found China 176: 1-3.
14. Liu Q, Liu G (2009) Using tasseled cap transformation of CBERS-02 images to detect dieback or dead Robinia Pseudacacia plantation. Inst Electr Electron Eng. pp: 11-15.
15. Dirr MA (1976) Selection of trees for toleration to salt injury. J Arboric, pp: 209-216.
16. Wang H, Pu R, Zhu Q, Ren L (2015) Mapping health levels of Robinia pseudoacacia forests in the Yellow River delta, China, using IKONOS and Landsat 8 OLI imagery. Int J Remote Sens 36: 1114-1135.
17. Vilková M, Tonika J, Müllerová J (2015) Black locust-Successful invader of a wide range of soil conditions. Sci Total Environ 505: 315-328.
18. Sabo AE (2000) Robinia pseudoacacia invasions and control in North America and Europe. Student On-Line 6: 1-9.
19. Jin TT, Liu GH, Fu BJ, Ding XH, Yang L (2011) Assessing adaptability of planted trees using leaf traits: A case study with Robinia pseudoacacia L. in the Loess Plateau, China. Chinese Geogr Sci 21: 290-303.
20. Liu X, Fan Y, Long J, Wei R, Kjelgren R, et al. (2013) Effects of soil water and nitrogen availability on photosynthesis and water use efficiency of Robinia pseudoacacia seedlings. J Environ Sci 25: 585-595.

21. Gilman EF, Watson DG (1994) Robinia pseudoacacia Black Locust.

22. Yuan-Xiu G, Gao-Huan Liu, Jin-Feng W (2001) Saline-alkali land in the Yellow River Delta: amelioration zonation based on J. Geogr Sci 11: 313-320.

23. Liang Z, Long Y (2010) Theory and Technology on Robinia Pseudoacacia Cultivation. China For, pp: 1-18.

24. Jian-Feng Z, Qi-Xiang S (2005) Causes of Wetland Degradation and Ecological Restoration in the Yellow River Delta Region. For Stud China 7: 15-18.

25. Xianzhao L, Chunzhi W, Qing S (2013) Screening for Salt Tolerance in Eight Halophyte Species from Yellow River Delta at the Two Initial Growth Stages. Int Sch Res Not, p: 8.

26. Schomaker ME, Zarnoch SJ, Bechtold WA, Latelle DA, Burkman WA, et al. (2007) Crown-Condition Classification: A Guide to Data Collection and Analysis.

27. Maas EV, Hoffman GJ (1977) Crop salt tolerance-current assessment. American Society of Civil Engineers for publication 103: 113-154.

28. Imada S, Iviatsuo N, Acharya K, Yamanaka N (2015) Effects of salinity on fine root distribution and whole plant biomass of Tamarix ramosissima cuttings. J Arid Environ 114: 84-90.

29. United States Department of Agriculture (1987) USDA Textural Soil Classification. Soil Mechanics Level I, pp: 3-11.

30. Schiefelbein JW, Benfey BN (1991) The development of plant roots: new approaches to underground problems. Plant Cell 3: 1147-1154.

31. Huang Y, Wang Y, Zhao Y, Xu X, Zhang J, et al. (2015) Spatiotemporal Distribution of Soil Moisture and Salinity in the Taklimakan Desert Highway Shelterbelt. Water 7: 4343-4361.

32. Gao P, Yang HL, Zhang GC, Zhou ZF (2008) Correlation of eco-hydrographic benefit and height increment of Robinia pseudoacacia stand with climatic environmental factors in Yellow River Delta Wetland of China. J For Res 19: 215-218.

33. Sawada H, Araki M, Chappell NA, LaFrankie JV, Shinizu A (2007) Forest Environments in the Mekong River Basin.

34. Davidson EA, Belk E, Boone RD (1998) Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. Glob Chang Biol 4: 217-227.

35. Allen CD (2009) Climate-induced forest dieback: an escalating global phenomenon? Unasylva 60: 43-49.

36. Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell N, et al. (2010) A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For. Ecol. Manage 259: 660-684.

37. Guarin A, Taylor AH (2005) Drought triggered tree mortality in mixed conifer forests in Yosemite National Park, California, USA. For Ecol Manage 218: 229-244.

38. Dale VH, Joyce LA, McNulty S, Neilson RP (2000) The interplay between climate change, forests, and disturbances. Sci Total Environ 262: 201-204.

39. Malhi Y, Aração LEOC, Gabraith D, Huntingford C, Fisher R, et al. (2009) Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest. Proc Natl Acad Sci USA 106: 20610-20615.

40. Rozas VF, Garcia-González I (2012) Too wet for oaks? Inter-tree competition and recent persistent wetness predispose oaks to rainfall-induced dieback in Atlantic rainy forest. Glob Planet Change 94-95: 62-71.

41. Jianfeng Z, Shangjun X (2009) Research on Soil Degradation of Robinia pseudoacacia Plantation under Environmental Stress. pp: 5-10.

42. Ranney TG (1990) Response of five temperate deciduous tree species to water stress. Tree Physiol 6: 439-448.

43. Fan C, Su C (2008) Effect of soil moisture content on the deformation behaviour of root-reinforced soils subjected to shear. Plant Soil 324: 57-69.

44. Kozlowski TT (1992) Sources and Sinks in Woody Plants Carbohydrate. Bot Rev 58: 107-222.

45. Loescher WH, Mccamant T, Keller JD (1990) Carbohydrate Reserves, Translocation, and Storage in Woody Plant Roots. HortScience 25: 274-281.

46. Archer J, Smith P (1972) The relation between bulk density, available water capacity, and air capacity of soils. J Soil Sci 23: 475-480.

47. Thomas PT (1989) Effect of varying soil moisture and bulk density of Teak, Eucalypt and Albizia root growth. For Stud China 7: 15-18.

48. Carter MR (1990) Relative Measures of Soil Bulk Density To Characterize Compaction in Tillage Studies on Fine Sandy Loams, Can J Soil Sci 70: 425-433.

49. Guo Y (2011) The relationship between ancient trees health and soil properties. African J Biotechnol 10: 17997-18004.

50. Goodman M, Ennos R (1999) The Effects of Soil Bulk Density on the Morphology and Anchorage Mechanics of the Root Systems of Sunflower and Maize. Ann Bot 83: 293-302.

51. Mohanty BP, Skaggs TH (2001) Spatio-temporal evolution and time-stable characteristics of soil moisture within remote sensing footprints with varying soil, slope, and vegetation. Adv Water Resour 24: 1051-1067.

52. Han G, Yu J, Li H (2012) Winter Soil Respiration from Different Vegetation Patches in the Yellow River Delta, China. Environ Manage, pp: 39-48.

53. Yasuhito S, Ichiro T, Tong-Hui Z (2004) Changes in Soil Properties after Afforestation in Horquin Sandy Land, North China. Soil Sci Plant Nutr 50: 537-543.