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Soil Properties across A Chronosequence of *Ailanthus altissima* in Semiarid Plantations

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ABSTRACT

Afforestation is a main tool for preventing desertification and soil erosion in arid and semiarid regions of Iran. Large-scale afforestation, however, has poorly understood consequences for the future ecosystems in the term of ecosystems protection. The objective of the present study is to identify changes in soil properties following different intervals of planting of *Ailanthus altissima* (tree of heaven) in semiarid afforestation of Iran (Chitgar Forest Park, Tehran). For this purpose, sand, silt and clay ratios, bulk density, soil moisture, pH, electrical conductivity, phosphorus, potassium, magnesium, calcium, sodium, total soil N, and total carbon was measured. Our study highlighted the potential of the invasive trees by *A. altissima*, to alter soil properties along chronosequence. Almost all soil quality attributes showed a declining trend with stand age. A continuous decline in soil quality indicated that the present land management may not be sustainable. Therefore, an improved management practice is imperative to sustain soil quality and maintain long-term productivity of plantation forests. Thinning activity will be required to reduce the number of trees competing for the same nutrients especially in a older stand to protect forest soils.

***Keywords*:** Afforestation; Forest Protection; Invasion species; Stand age; Tree of heaven

1. Introduction

Afforestation and reforestation are important activities for restoration of terrestrial ecosystem productivity in arid and semiarid regions[1,2]. Overuse of forests and other vegetation has resulted in large areas of barren land and depletion of soil cover, risking permanent loss of the productive capacity of the land[3]. Hundreds of tree species have been widely-planted for many purposes including erosion, sand control, supply of fuelwood and other products[4-6]. If planted with thoughtful planning, trees can improve both the aesthetic environment and the local climate in urban areas and help to protect the forest ecosystem functions[7,8].

Ailanthus altissima (Mill., tree of heaven) is a native tree of China that has become established throughout many regions of the world (e.g., USA, Canada, Argentina, Poland, Germany, New Zealand, Morocco, Japan, and Iran; see[6,9,10]. This is found invading temperate ecosystems worldwide. This species is a fast growing tree, a prolific seed producer, a persistent stump and root sprouter and an aggressive competitor with respect to the surrounding vegetation.[11,12] suggested that *A. altissima* was able to withstand the prolonged dry seasons and also, dry soils are probably more suitable for its growth than wet soils. Furthermore, this tree does well on very poor soils, and tolerating a pH of less than 4.1[13]. *A. altissima* has been planted widely in urban areas because of its ability to tolerate atmospheric pollution and it is highly resistant to SO_2[14]. However, cultivation outside of cities may foster invasions of adjacent near-natural or natural habitats[15-18]. In Iran, *A. altissima* was introduced during the 20th century for ornamental purposes, and they are now spreading across Iran. To our knowledge, no one has yet measured the effects of *A. altissima* on soil properties across a chronosequence.

In many ecosystems, especially in semiarid climates, vegetation productivity may be limited by nutrient availability[19,20]. In general, biomass and soil nutrients change substantially with plant age, and nutrient limitation is common during plant growth[21]. However, the authors are unaware of research examining how *A. altissima* invasion affects on soil characteristics across a chronosequence.

The magnitude and direction of the effect of exotic invasive trees on soil characteristics may depend on the invasive species and the invaded community[22]. However, the link between invasion and soil properties remains largely unexplored. Hence, the objective of the present study is to identify changes in soil properties following different intervals of planting of A. altissimia in semiarid afforestation of Iran.

2. Materials and Methods

2.1 Site description

The study was conducted at a Chitgar Forest Park situated at 35°42′N, 51°08′E, approximately 8 km from the west of Tehran city, capital of Iran (**Figure 1**). Chitgar Forest Park covers an area of about 14.5 square kilometers[23,24]. Elevation varies between 1225 and 1313 M.AS.L. The site receives a total annual rainfall of 276 mm and the average temperature is 17.2 °C . Mean annual number of rainy days is about 70 and mean annual relative humidity is 39.8%[25].

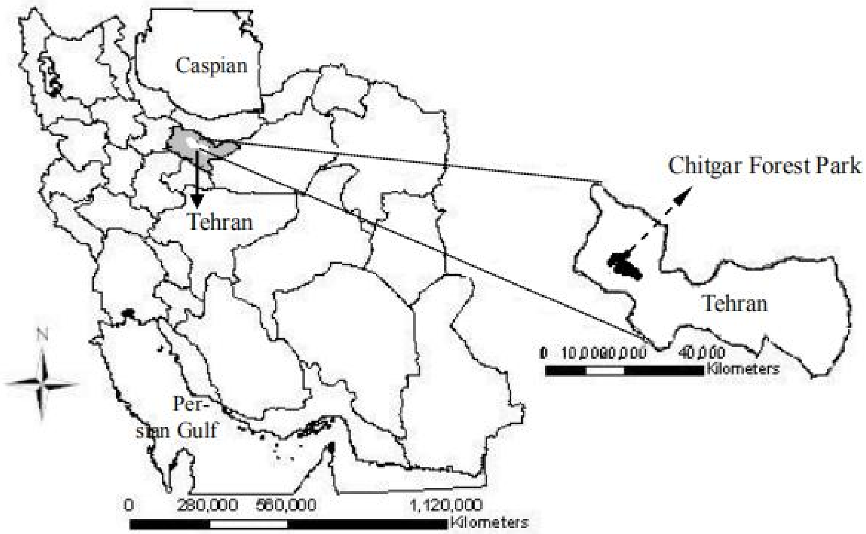

Figure 1; Map showing the location of the study area in the Tehran province of Iran**.**

2.2 Plot establishment and soil sampling

The initial soil conditions were considered to be similar for all stands, as the terrain was undulating with a slope of less than 4°[26]. Three independent stands of different-aged *A. altissima* were located in Chitgar Forest Park were selected (**Table 1**). The three stands began as *A. altissima* afforestations planted in 1975 (hereafter PI), 1985 (hereafter PII), and 1995 (hereafter PIII). All stands were established using the same site preparation methods. Tree diameter at breast height (DBH) was measured for each tree. Ten 20 × 20 m plots were randomly established for each stand age. Soil samples were collected from the 4 corners and the center of each square plot. Soil samples were taken at two different depths (0–15 cm and 15–30 cm) using a soil auger[26].

Stand parameters	**PI**	**PII**	**PIII**
Stand Age (years)	40	30	20
Mean DBH (cm)	25	18	13
Tree height (m)	6.0	5.2	4.7
Stand density (stem ha^{-1})	900	980	1100
Canopy cover (%)	39^{*}, $22^{\times}$	35^{*}, $18^{\times}$	35^{*}, $15^{\times}$
Mean crown length (m)	1.7	1.4	1.3
Mean bark thickness (cm)	1.2	1.0	0.7
LAI (m^2 m^{-2})	2.02	2.16	2.50

*leafed and $^{\times}$leafless periods.

Table 1. Stand characteristics of the three *Ailanthus altissima* plots in the Chitgar Forest Park (CFP)

2.3 Plot establishment and soil sampling

Soil samples were sieved through 2 mm sieves. Sand, silt and clay ratio of soil samples in the laboratory were found by Bouyoucos hydrometer method[27]. Also, bulk density, soil moisture, pH and electrical conductivity (EC) values were measured. Soil samples were analyzed from solution analysis by inductively coupled plasma mass spectrometry (ICP) for phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na). The pH was determined using a Mehlich buffer method with water[28]. Total soil N was determined using the Kjeldahl method where samples were subjected to acid digestion, distillation, and titration, as described by Foster [29]. Total carbon was measured by using an SSM- 5000A TOC-5000 analyzer[30].

2.4 Statistical analysis

Normality of data was explored by Kolmogorov-Smirnov tests, then one-way analysis of variances (ANOVA) tested significant differences in soil characteristics among the plots. Once a significant difference was detected, Tukey honest significant difference (HSD) tests were applied. The paired t-test was used to compare means between soil depths. Statistical analysis was performed using SPPS ver. 22.

3. Results and Discussion

Soil texture according to plantation age is shown in **Table 2.** No significant difference between stands for soil bulk density at 0–15 cm depth was observed (Table 2). Regarding the 15-30 cm soil depth, significant increase in bulk density was observed between the youngest and middle-aged to oldest stand (Table 1). Bulk density increased with depth of soil (Table 2). Only the oldest stand had significant difference between soil depths (Table 2). In this study, a similar increase in soil bulk density was found amongst chronosequnces (Table 2), implying that plantation establishment failed to improve the physical condition of the soil. This may be related to the development of the root systems and the presence of microorganisms, like those find by scientsit[26,31]. It should be noted that a longer time period is required for resulting any substantial changes in soil bulk density[32,33].

The soil underlying the oldest stand (PI) showed the highest clay percentage in both depths, according to past research[34]; whereas the highest percentage of silt was recorded in the middle-aged stand (PII) in both depths (Table 2). Meanwhile, at 0-15 and 15-30 cm depths, the oldest and youngest stand had the highest sand percentage (**Table 2**).

Properties	Soil depth (cm)	Chronosequence		
		PI	PII	PIII
Bulk density (g cm^{-3})	0-15	1.30 ± 0.08^{a1}	1.12 ± 0.07^{a1}	1.03 ± 0.03^{a1}
	15-30	1.43 ± 0.10^{a2}	1.19 ± 0.04^{b1}	1.09 ±0.05^{b1}
Sand (%)	0-15	53.72	54.60	57.33
	15-30	58.63	56.11	57.92
Clay (%)	0-15	21.50	18.46	16.99
	15-30	21.66	18.74	17.07
Silt (%)	0-15	24.78	26.94	25.68
	15-30	19.71	25.15	25.01

Table 2. Soil physical properties of *Ailanthus altissima* at different plantation ages

Values are means ± standard error. Means within rows with different letters indicate significant difference between chronosequences by Tukey-test at $P < 0.05$, while means within columns with different numbers indicate significant difference between soil depths by independent t-test at $P < 0.05$.

Soil pH decreased significantly for both soil depths during chronosequences (**Table 3**). Significant reduction in pH was observed in older stands as compared to the youngest stand (Table 3). The soil pH values in the four sites are typical for the calcareous soils in semiarid plantations in Iran[35]. In the present study, soil pH declines with stand age (Table 3), according to past research[26,34]. Reduction in soil pH in the older stands of this study was probably related to vegetative coverage, which caused extensive secretion of organic acids associated with accelerated organic matter decomposition. In other hands, The reduction in soil pH was probably related to vegetative cover because the extensive secretion of organic acids and the release of CO_2 from roots and/or microorganisms can led to decrease in pH[36]. Decrease in soil pH has often been found to be the result of plantation establishment[26,37,38,39].

EC in PIII were significantly higher than PII and PI in both soil depths (**Table 3**). The soil EC in our study was consistent with the finding of[40] that the soil EC in the youngest stand was smaller than that in the middle or oldest stand, which could be attributed to the previous fertilizer application during the plantation establishment.

Properties	**Soil depth (cm)**	**Chronosequence**		
		PI	**PII**	**PIII**
pH	0-15	6.92 ± 0.12^{a1}	7.16 ± 0.16^{b1}	7.59 ± 0.12^{c1}
	15-30	7.03 ± 0.10^{a1}	7.24 ± 0.19^{b1}	7.64 ± 0.15^{c1}
EC (ds m^{-1})	0-15	0.79 ± 0.03^{a1}	0.76 ± 0.03^{a1}	0.64 ± 0.03^{b1}
	15-30	0.98 ± 0.05^{a1}	0.88 ± 0.04^{a1}	0.74± 0.04^{b1}
Total N (g kg^{-1})	0-15	0.07 ± 0.01^{b1}	0.10 ± 0.01^{ab1}	0.17 ± 0.02^{a1}
	15-30	0.03 ± 0.01^{b2}	0.06 ± 0.01^{ab2}	0.10 ± 0.01^{a2}
Total C (g kg^{-1})	0-15	2.06 ± 0.25^{a1}	1.93 ± 0.17^{ab1}	1.67 ± 0.09^{b1}
	15-30	1.72 ± 0.19^{a2}	1.19 ± 0.19^{b2}	1.16 ± 0.16^{c2}
C/N ratio	0-15	29.4 ± 1.39^{a1}	19.3 ± 1.44^{b1}	9.8 ± 1.01^{c1}
	15-30	57.3 ± 2.96^{a2}	19.8 ± 1.50^{ab1}	11.6 ± 1.25^{b1}
P (mg g^{-1})	0-15	0.76 ± 0.07^{a1}	0.72 ± 0.02^{a1}	0.61 ± 0.04^{b1}
	15-30	0.82 ± 0.04^{a1}	0.73 ± 0.02^{a1}	0.64 ± 0.05^{b1}
K (mg g^{-1})	0-15	0.17 ± 0.01^{b1}	0.14 ± 0.01^{a1}	0.24 ± 0.01^{a1}
	15-30	0.14 ± 0.01^{b1}	0.15 ± 0.01^{B1}	0.23 ± 0.01^{a1}
Mg (mg g^{-1})	0-15	0.53 ± 0.06^{b1}	0.64 ± 0.09^{b1}	0.79 ± 0.11^{a1}
	15-30	0.74 ± 0.10^{b2}	0.72 ± 0.07^{b1}	0.96 ± 0.13^{a1}
Ca (mg g^{-1})	0-15	196.1 ± 13.7^{b1}	198.3 ± 10.6^{b1}	243.1 ± 15.6^{a1}
	15-30	187.5 ± 16.4^{c1}	202.2 ± 9.4^{b1}	245.6 ± 19.8^{a1}
Na (meq l^{-1})	0-15	2.12 ± 0.14^{a1}	2.14 ± 0.11^{a1}	2.06 ± 0.24^{a1}
	15-30	2.15 ± 0.27^{a1}	1.94 ± 0.15^{a1}	1.99 ± 0.09^{a1}

Table 3. Soil chemical properties of *Ailanthus altissima* at different plantation ages

Values are means ± standard error. Means within rows with different letters indicate significant difference between chronosequences by Tukey-test at $P < 0.05$, while means within columns with different numbers indicate significant difference between soil depths by independent t-test at $P < 0.05$.

Total N in PI was significantly higher than PIII in both soil layers (Table 3). T-test suggested that Total N (%) in the deeper soil has significantly lower than in the upper soil for all plots (Table 3). After vegetation plantation, soil nutrients usually increase[31,41]. In our results, P, K, and Na greater in PI compared with other plots, whereas total N, Mg, and Ca were greater in PIII soils. The main difference in soil properties among stands in the chronosequence was the greater total N in PIII compared with PI. Total N has been regarded as indicator of soil fertility and productivity[42], Hence, our present results indicate that the development of *A. altissima* on Chitgar Forest Park resulted in significant decline of soil fertility. Total N in PI was significantly higher than PIII in both soil layers (Table 3), and its mean an increase in soil salinity[43].

Total C significantly increased with stand age in both soil layers (Table 3). The higher concentration of total C in the soil surface layer in the plantations in contrast to moving sand dunes was probably due to the increased litter inputs, low incorporation rate of surface litter into soil by soil fauna, reduced rate of soil erosion, and low mineralization rate of C because of the high phenol and lignin contents in litter[30].

C/N also increased along a chronosequence (Table 3).[44] reported that soils with C/N below 20 could offer sufficient N for plant uptake; thus our result on the soil C/N of the PII and PIII suggests that the youngest and middle-aged stand can provide adequate N for the associated plants to be recovered.

Significant increase in P was observed in PIII as compared to PI and PII in both soil depths (Table 2). P in the soil was reduced as the stand aged (Table 3), probably as the result of the huge nutrient consumption ensuing from the vigorous growth of *A. altissima*[26] reported. This finding is similar to other research about plantation along a chronosequence[26,30].

K, Mg and Ca in PIII were significantly higher than PII and PI in both soil depths (Table 3), indicating an accumulation of soil cations along a chronosequence of *A. altissima* plantations [45]. No significant trends in Na were observed among chronosequences or soil layers (Table 3). NA ions are less tightly held to soil particles than K, Ca or Mg. Therefore, Na is more easily leached from soil than the other cations[46].

4. Conclusion

In conclusion, our study highlighted the potential of the invasive trees by *A. altissima*, to alter soil properties along chronosequence. Almost all soil quality attributes showed a declining trend with stand age. A continuous decline in soil quality indicated that the present land management may not be sustainable. Therefore, an improved management practice is imperative to sustain soil quality and maintain long-term productivity of plantation forests. Thinning activity will be required to reduce the number of trees competing for the same nutrients especially in PII and PI stands. Consequently, this kind of afforestation is not the most efficient procedure either in the long-term or in the mid-term to improve land cover in non-degraded landscapes with the aim of soil and plant conservation, but for short period is appropriate.

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