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Effects of Oxidized Brown Coal Humic Acid Fertilizer on the Relative Height Growth Rate of Three Tree Species

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Abstract: This study aimed to identify the effects of oxidized brown coal humic acid fertilizer on the relative growth rate of several tree species intended for reforestation. Field experiments were carried out during 2011–2014 at the Research and Experimental Center for Combating Desertification located at the Elsen Tasarkhai station in central Mongolia. The trees studied were *Populus sibirica* Tausch., *Salix ledebouriana* Trautv., and *Acer tataricum* L. The experiment was conducted with concentrations of 2000, 10,000, and 20,000 mg L^{-1} of humic acid fertilization treatment. Measurement of the relative height growth rate (RHGR) was undertaken for a period of four years. The results demonstrated significant differences between the humic fertilizer concentrations, which varied depending on the species. Compared to monthly RHGR over the study period, the treatment using fertilizers yielded significantly better tree growth. *P. sibirica*, when treated with 2000 mg L^{-1} and 10,000 mg L^{-1} humic acid fertilizers, had significant height growth rates. *S. ledebouriana* with 20,000 mg L^{-1} of humic acid fertilzers treatments showed the highest RHGR. In addition, when the humic acid treatments were compared to the control, results showed that oxidized brown coal humic acid fertilizers as an organic fertilizer can have a significant effect on the growth of *A. tataricum*. The results equally showed that the soil chemical properties EC, CO_2, NO_3, and K_2O were significant among all the treatments compared to control. The effect on P_2O_5 significantly increased in all the treatments; however, there was no significant effect on pH and Mg among all treatments. Combining the results obtained with reforestation and sustainable land-management practices can help to improve soil organics in degraded sandy soil regions.

Keywords: reforestation; humic acid fertilizer; relative height growth rate; soil chemical properties

1. Introduction

Scientific research has established that organic matter plays an important role in controlling the physiochemical properties of soils [1,2]. Residues from the partial oxidation of the dead biomass of plants is considered to be the source of organic substances that are added to soil as humus [3–5]. Currently, there is an increase in the quantity of humic-based products available to plant growers. These have various sources, ranging from hard black coal that is composted with plant matter and manure to complex and richer humic sources such as brown coal, peat, and leonardite [4,6,7]. Leonardite is a medium-brown coal that contains the most complex and bio-active form of humic components [8]. Humic substances (HS) are the major organic components of the Earth's soils and sediments that were created from decayed bio matter by a process called humification [1]. HS are found in especially high concentrations in peat and brown coals [9]. Different grades of coal are formed by the geological compression of soil layers over millions of years. The lower ranks of coal such as lignite (brown coal) and sub-bituminous coals are not efficient as fuel for energy but contain large amounts of organic matter [10]. During humification, with the aid of millions of micro-organisms, the simple products of decomposition like amino acids, carbohydrates and phenols turn into very complex, long-chain organic compounds with high molecular weight called humic acids (HA) that are derived from vegetation. This material is very rich and beneficial for plant growth as an environment-friendly resource [11]. HAs are complex molecules that exist naturally in soils, peats, oceans and fresh water [12,13]. The best source of HAs is the soft sedimentation layers of leonardite, an organic material found beneath the Earth's surface in the cold climes of the United States, Russia, and Mongolia [14]. Often referred to as oxidized lignite, these layers are the richest as well as the most economical source of HA from leonardite, a naturally occurring oxidized form of lignite coal [15,16]. HS are the subject of research in different fields of agriculture that include soil chemistry, fertility, plant physiology, and environmental sciences. This is due to the multiple roles played by these substances that have highly beneficial effects on plant growth directly or indirectly [4,17,18]. HS are the end products of the organic decomposition of biotic compounds constituting between 50–90% of the organic matter of peat, lignite, sapropels, and the non-living organic matter of soil and water ecosystems [19–21]. These substances play a vital role in the soil's function and structure [22]. They can be useful for living organisms in developing food, enzyme metabolism and substrate material, as a carrier of nutrition, as catalysts of biochemical reactions, and in antioxidant activity [23–25]. It has been argued that HS can both directly and indirectly affect the physiological processes of plant growth.

Commercial products derived from lignite, sold mainly as humate preparations, have been widely developed as plant-growth stimulants aimed at increasing crop yield [3,26]. These products are also claimed to improve key indicators of soil health including soil pH and microbial biomass [27]. The sorption of sulfathiazole through three structural analogs to leonardite HA has been investigated in single and binary solute systems in order to elucidate the sorption mechanism of sulfonamides in soil organic matter. High-affinity cation binding explains the absorption and adsorption of polar sulfonamides within crop soils and the strong relationship of adsorption and absorption on soil organic matter content and pH [28]. It is difficult to identify the difference between the direct and indirect effects of these substances. In fact, some of their positive consequences can be assigned to general enrichment of the soil's fertility and hence the higher availability of nutrients [29]. Mongolian hereditary manure has traditionally been used for farming, but other types of fertilizer used in neighboring countries are also imported. Rapid population growth, desertification, and land degradation means that it is necessary in reforestation and agriculture to improve the productivity of locally produced low-cost, environmental friendly bio-fertilizer use. In Mongolia, there are several mines and seams of carbon-rich mineral deposits containing good agricultural-grade humic substances [30,31]. A study by the Mongolian Academy of Sciences, Institute of Chemistry and Chemical Technology, on the non-energy derived from oxidized brown coal humic fertilizers was used in our experiment. Locally produced brown coal humic soil fertility is useful for reforestation, impact identification and achieving desirable volume suitable for fertilization. HA can reduce the use of the chemical fertilizers that cause environmental pollution, and the lower expenditure of these fertilizers consequently means lower costs [7,32]. The aim of this study was to determine the effects on reforestation activity of non-energy derived from oxidized brown coal HS in a degraded sandy soil region. In reforestation applications, HS have the advantage that they are 100% organic, compatible with sustainable land-management practices, and help to address environmental issues such as desertification and land degradation.

The present study highlights plant-growth promoting oxidized brown coal as an alternative to fertilizers that is also environmental friendly.

2. Materials and Methods

2.1. Study Area

This study was carried out at Elsen Tasarkhai station of the Research and Experimental Center for Combating Desertification (47°27′ N, 103°68′ E; 1967 m a.s.l), located in Khugnu-Tarna National Park in the Rashaant district of Bulgan province, central Mongolia. Summary of ecosystem chracteristics and soil chemical and physical properties of the research area shown in Table 1. The study area has a semi-arid continental climate that is characterized by average annual minimum and maximum temperatures of 22 °C and −20 °C, respectively, whereas the maximum absolute temperature is 36 °C, and the mean annual precipitation has been reported to be 200–250 mm [33]. The soils at forest-steppe and steppe were soil taxonomy a higher aridity index, classified as Calcic Kastanozems and Calcic Hyposodic Kastanozems, respectively [34,35]. Soil physical properties in the clay 5.57%, silt 4.73% and sand 89.7%, structures sandy loam with a pH range between 7.80 and 8.92 [33].

Table 1. Summary of chracteristics of the study site.

Chracteristics	
Ecosystems	Semi arid areas
Location	103°68′ E and 47°27′ N
Elevation	1967 m a.s.l
Major vegetation species	*Caragana microphylla*, *Artemisia frigida*, *Poa attenuata* and *Agriophyllum pungens*
Land use change history	Livestock
Land use management	Khognokhaan Natural Reserve
Local ecosystems problem	Mitigating sand movement in the region with soil erosion/desertification
Climat condition	
Mean annual temperature	−2 °C, ranges from −20 °C to 22 °C
Mean annual precipitation	200 to 250 mm
Wind velocity ranges	0.5 to 2.3 m/s with the maximum in May about 4.0 m/s
Soil physical properties	
Sand (%)	89.7
Silt (%)	4.73
Clay (%)	5.57
Soil chemical properties	
pH (1:2.5)	8.42
Salt (%)	0.06
Electric conductivity (dS/m)	6.42
Organic matter (%)	0.63

Source: Khaulenbek et al. (2010) [33].

The study area is located surrounding the boundary between forest-steppe and dry steppe zones, based on the plant geographical classification in Mongolian [36].

2.2. Experimental Design

This study was conducted in 2011–2014 by the Mongolian Academy of Sciences, (Institute of Chemistry and Chemical Technology) on the non-energy derived from oxidized brown coal humic acid fertilizers. Humic acid fertilizers were used with the following characteristics (wt %): carbon (C) 60.5; hydrogen (H) 3.9; nitrogen (N) 0.9; oxygen (O) 34.7, respectively [37]. These concentrations were approximately equivalent to field application rates of 2000 mg L^{-1}, 10,000 mg L^{-1}, and 20,000 mg L^{-1}

oxidized brown coal humic fertilizers m^2 yr^{-1}. Humic acid fertilizers mixed with water were used for irrigation twice during the growing seasons for four months with a watering can, using 100 liters of water with 20 g, 100 g, and 200 g of humic acid per solution preparation. Ten-liter sprays were used for each 1 m^2 area every time, with irrigation undertaken in a flooding manner. Three-year-old *Populus sibirica* Tausch., *Salix ledebouriana* Trautv., and *Acer tataricum* L. species were used as deciduous trees and shrubs for the monitoring studies. *P. sibirica*, *A. tataricum*, and *S. ledebouriana* are widely distributed natural trees in Mongolia and are the most widely used trees in reforestation [38,39]. This study comprised of a repeated measure design involving a total of 120 trees having four treatments, $HA_{0.2}$ (2000 mg L^{-1}), HA_{10} (10,000 mg L^{-1}), and HA_{20} (20,000 mg L^{-1}) along with control HA_0 (without fertilizer). Each treatment has three different tree species (*P. sibirica*, *S. ledebouriana*, and *A. tataricum*) with a total of 30 trees per replicate. Trees were planted with spacings of 2 × 1.5 m. Tree height growth was measured twice a year (Spring and Autumn), and soil analysis was carried out in September 2014. The soil samples for each treatment were collected from three subplots with three replications. A total of 36 samples having four treatments (4 treatments × 3 subplots × 3 replication × 1 mixed soil layer (0–30 cm)). The surface soil (0–30 cm) were collected at depths of 0–10, 10–20, and 20–30 cm using a core sampler (7 cm diameter by 10 cm height) and thoroughly mixed to form a homogeneous sample for analysis. Soil chemical properties were analyzed at the soil laboratory in the Institute of Geography and Geoecology. The soil samples were air dried and sieved through 2 mm-mesh size stainless steel sieve and stored in polyethylene bags until analysis. Particle size distributions of the soil samples were determined by using the hydrometer method, soil pH and electrical conductivity (EC) in a 1:2.5 soil: water (w:v) extract [40]. Soil car bonate (CO_2) was determined through the pressure-calcimeter method and organic matter (OM) content using the Walkley–Black method [41,42]. Assimilable phosphoric acid (P_2O_5) and potassium oxide (K_2O) were determined by the Olsen method using a spectrophotometer [43]. Exchangeable magnesium (Mg) and calcium (Ca) were determined with an atomic absorption spectrometer, and nitrate (NO_3) content was determined by the titration method [43].

2.3. Statistical Analyses

Since growth may be related to initial tree size at the beginning of the growth period, relative height growth rate (RHGR) was calculated using the equation below. In the first estimator, tree height is averaged before in-transforming, whereas in the second estimator, the height is in-transformed before averaging. The RHGR was computed according to the following equation:

$$\text{RHGR} = \frac{1n\ HT_2 - 1n\ HT_1}{t_2 - t_1}$$

where *n HT* is the natural logarithm of tree height; *t* is the time (in months); and the subscript refers to initial and final tree height [44–46]. The relative growth rate (RHGR) of *P. sibirica*, *S. ledebouriana* and *A. tataricum* and soil data were statistically analyzed by one-way analysis of variance (ANOVA) followed by the homogeneity of variance which was verified using Levene's test which failed (for RHGR, the homogeneity test failed for *S. ledebouriana* and for soil data Ph, OM, NO_3, P_2O_5, K_2O, Ca, Mg). Hence, Kruskal Wallis non-parametric analysis was used as an alternative (Kruskal and Wallis, 1952). Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS) Version 21 (IBM Corp., New York, NY, USA). Statistical significance was accepted at $p < 0.05$.

3. Results

3.1. Relative Height Growth Rate (RHGR) during Monitoring Period

The relative height growth rate (RHGR) showed significant differences for the treatments with increased exposure to brown coal humic fertilizer compared to control treatments (Table 2).

Table 2. Effect of humic fertilization on the relative height growth rate (RHGR) of *Populus sibirica*, *Acer tataricum*, and *Salix ledebouriana*.

Speices	Treatments	Years			
		2011	2012	2013	2014
		Relative Height Growth Rate (cm month^{-1})			
P. sibirica	HA_0	5.62 ± 0.89 ^{b}	5.32 ± 0.85 ^{b}	5.99 ± 0.79 ^{b}	6.57 ± 0.89 ^{b}
	$HA_{0.2}$	8.30 ± 0.63 ^{a}	7.79 ± 0.60 ^{a}	9.12 ± 0.60 ^{a}	9.25 ± 0.63 ^{a}
	HA_{10}	7.98 ± 0.77 ^{a}	7.70 ± 0.67 ^{a}	7.23 ± 0.77 ^{ab}	8.15 ± 0.67 ^{ab}
	HA_{20}	6.24 ± 0.62 ^{ab}	5.92 ± 0.43 ^{ab}	7.18 ± 0.67 ^{ab}	7.61 ± 0.47 ^{ab}
A. tataricum	HA_0	6.74 ± 0.74 ^{a}	5.12 ± 0.89 ^{b}	3.54 ± 0.61 ^{b}	2.45 ± 0.70 ^{b}
	$HA_{0.2}$	6.53 ± 0.68 ^{a}	5.49 ± 0.79 ^{ab}	4.15 ± 0.56 ^{ab}	3.32 ± 0.85 ^{b}
	HA_{10}	7.10 ± 0.65 ^{a}	7.48 ± 0.77 ^{a}	5.59 ± 0.85 ^{a}	5.61 ± 0.47 ^{a}
	HA_{20}	7.54 ± 0.60 ^{a}	7.80 ± 0.63 ^{a}	5.97 ± 0.59 ^{a}	5.70 ± 0.67 ^{a}
S. ledebouriana	HA_0	5.87 ± 0.79 ^{b}	6.07 ± 0.38 ^{b}	5.90 ± 0.70 ^{b}	6.53 ± 0.63 ^{a}
	$HA_{0.2}$	6.84 ± 0.17 ^{b}	6.41 ± 0.40 ^{b}	7.51 ± 0.61 ^{ab}	6.97 ± 0.48 ^{a}
	HA_{10}	6.91 ± 0.49 ^{b}	6.62 ± 0.81 ^{b}	6.90 ± 1.50 ^{ab}	7.88 ± 0.54 ^{a}
	HA_{20}	9.97 ± 1.61 ^{a}	8.36 ± 0.57 ^{a}	9.91 ± 1.61 ^{a}	8.52 ± 1.16 ^{a}

Data are shown as mean ± SEM; mean followed by the same letters are not significantly different at the 0.05 level (Duncan's multiple range test). Mean of three different rates of humic addition: control HA0 (0 mg L^{-1}), HA0.2 (2000 mg L^{-1}), HA10 (10,000 mg L^{-1}), and HA20 (20,000 mg L^{-1}) of oxidized brown coal humic fertilizers m^{2} yr^{-1}, respectively.

The RHGR of *P. sibirica* increased significantly with $HA_{0.2}$ treatment compared to H_0 treatment during the years studied. With HA_{10} treatment (2011–2012) the RHGR of *P. sibirica* increased significantly compared to the H_0 treatments. For 2013–2014, the RHGR of *P. sibirica* showed no sigificant differences with the HA_{10} and H_0 treatments. The RHGR level of *P. sibirica* was not significantly different for all treatments within the study period, with the addition of the H_{20} treatment being comparative to the HA_0 treatment. In the course of the survey, the *P. sibirica* RHGR range was 5.32 ± 9.25 cm month^{-1} or uneven growth.

The RHGR level was significantly larger for the treatments with increased exposure to brown coal humic fertilizer as compared to the control treatments (Table 1). The RHGR of *A. tataricum* significantly decreased over the years (6.74, 5.12, 3.54, and 2.45 cm month^{-1}, respectively). However, in 2011 the RHGR was not significantlyaffected, and in 2012, 2013, and 2014, there was a rapid increase in RHGR for HA_{10} and HA_{20} treatments. In the course of the survey, the *A. tataricum* RHGR range was 2.45 ± 7.80 cm month^{-1}, or uneven growth.

The RHGR of *Salix ledebouriana* was significantly moderate for the treatments with increased exposure to brown coal humic fertilizer compared to control treatments (Table 1). The highest RHGR increase was observed in HA_{20} in brown coal humic acid fertilizer treatments between 2011 and 2013. However, the HA_{10}, $HA_{0.2}$ and HA_0 treatments had less effect on RHGR over the years. There were no significant differences in the treatments within 2014 and, in comparison with other years all treatments had significantly increased RHGR. In the course of the survey, the *S. ledebouriana* RHGR range was 2.45 ± 7.80 cm month^{-1} or uneven growth.

3.2. The Comparative Analysis of RHGR during Monitoring Period

The response of humic acid application and different treatments on plant growth characteristics is presented in Figure 1.

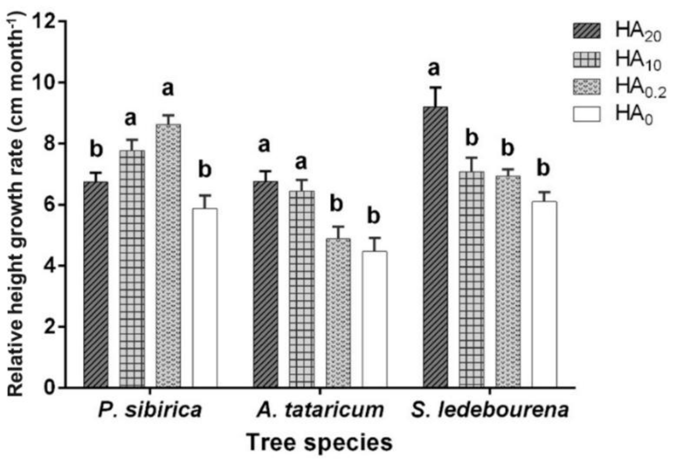

Figure 1. The comparative analysis of different treatment and years with RHGR. Humic acid was applied at HA_{20} (20,000 mg L^{-1}), HA_{10} (10,000 mg L^{-1}), $HA_{0.2}$ (2000 mg L^{-1}), and HA_0 (0 mg L^{-1}) oxidized brown coal humic fertilizers m^2 yr^{-1}, respectively. Mean followed by the same letters are not significantly different at the 0.05 level (Duncan's multiple range test).

Results indicate that humic acid treatments significantly increased the relative height growth rate of trees during the four-year period. Based on the increment observed, the RHGR mean ratios obtained for *P. sibirica*, *A. tataricum*, and *S. ledebouriana* were 7.25, 5.63, and 7.32 cm $month^{-1}$, respectively. The interaction effect between oxidized brown coal humic fertilizers with trees RHGR from the HA_{20}, HA_{10}, $HA_{0.2}$ and HA_0 treatments for each area was evaluated by comparing the highest between *S. ledebouriana* and the *A. tataricum* alternative; humic acid is shown to lower the intensity of the norm, with the *P. sibirica* $HA_{0.2}$ and HA_{10} scenario showing the highest intensity value (Figure 1). In the comparative analysis of *A. tataricum*, when treated with HA_{10} and HA_{20} treatments, had shown significant RHGR. The different *S. ledebouriana* RHGR traits ranged from 6.09 to 9.19 cm $month^{-1}$, with the values of HA_0, $HA_{0.2}$ and HA_{10} treatments being the lowest and those of the HA_{20} treatments being the highest.

3.3. Effect of Soil Chemical Properties on Fertilization

The effect of oxidized brown coal humic acid fertilization treatments on soil chemical properties was significantly affected ($p < 0.05$) compared to control treatment (Table 3).

Table 3. Soil chemical property of soil following brown coal humic acid fertilizer application.

Treat	pH	EC	CO_2	OM	NO_3	Assimilable		Exchangeable	
						P_2O_5	K_2O	Ca	Mg
HA_0	8.32 ± 0.04 ᵃ	7.58 ± 0.54 ᶜ	0.75 ± 0.48 ᵃ	0.39 ± 0.01 ᵇ	0.96 ± 0.02 ᵃ	0.86 ± 0.04 ᵈ	10.22 ± 0.70 ᵇ	8.60 ± 0.17 ᵃ	3.20 ± 0.14 ᵃ
$HA_{0.2}$	8.25 ± 0.08 ᵃ	9.92 ± 0.23 ᵇ	0.45 ± 0.01 ᵇ	0.41 ± 0.01 ᵇ	0.70 ± 0.06 ᵇ	1.66 ± 0.10 ᶜ	17.22 ± 0.43 ᵃ	7.00 ± 0.40 ᵇ	4.20 ± 0.15 ᵃ
HA_{10}	8.23 ± 0.08 ᵃ	11.4 ± 0.16 ᵃ	0.37 ± 0.01 ᶜ	0.57 ± 0.03 ᵃ	0.71 ± 0.04 ᵇ	2.24 ± 0.18 ᵇ	17.44 ± 0.64 ᵃ	8.52 ± 0.23 ᵃ	3.52 ± 0.22 ᵃ
HA_{20}	8.23 ± 0.11 ᵃ	9.92 ± 0.32 ᵇ	0.40 ± 0.01 ᵇᶜ	0.42 ± 0.02 ᵇ	0.69 ± 0.02 ᵇ	2.88 ± 0.14 ᵃ	16.25 ± 0.61 ᵃ	6.74 ± 0.43 ᵇ	4.24 ± 0.28 ᵃ

Data are shown as means ± SEM; pH and EC (1:2.5) (dS/m^{-1}); CO_2 and OM (g kg^{-1} % s.s); P_2O_5, K_2O, Ca, and Mg (meq 100 g^{-1}); mean followed by the same letter stands for not significantly different at 0.05 level (Duncan's multiple range test). Mean of three different rates of humic addition: control HA0 (0 mg L^{-1}), $HA_{0.2}$ (2000 mg L^{-1}), HA_{10} (10,000 mg L^{-1}), and HA_{20} (20,000 mg L^{-1}) of oxidized brown coal humic fertilizers m^2 yr^{-1}, respectively.

According to the analysis results, the treatments of $HA_{0.2}$,HA_{10}, HA_{20} significantly increased the EC, and K_2O, but significantly reduced CO_2 and NO_3 contents compared to the control treatments. P_2O_5 was statistically significant and increased among all the treatments. pH and Mg were not significantly affected much by all the treatments. In the HA_{10} treatment, OM significantly increased compared to the control treatment, but there was no significant increase in the $HA_{0.2}$ and HA_{20} relatively. In the $HA_{0.2}$ and HA_{20} treatments, Ca significantly decreased as compared to the HA_0 treatment.

4. Discussion

The findings from this study suggest that humic acid fertilizer concentrations had a significant effect on all growth traits with the treatments of HA_{20}, HA_{10}, $HA_{0.2}$, and HA_0. Monthly RHGR during the study years showed that trees treated with humic fertilizer treatments grew significantly more. The study showed increased HS concentration with significant monthly increase in RHGR of *P. sibirica* and *S. ledebouriana* species. In other related experimental studies, HA application increased the cumulative effect was the enhanced growth of plants and an increased yield of dry matter [47–52]. The increase of root growth in most cases is more visible than the stimulation of shoot growth [50,53]. Studies on the effects of HS on plant growth, under conditions of adequate mineral nutrition, consistently show positive effects on plant biomass [13,51]. Overall, random effects meta-analysis estimated a shoot dry weight increase of 22% and a root dry weight increase of 21% in response to HS application [3]. This study showed that, RHGR of *A. tataricum* significantly decreased over the years with HA_0 treatments. *A. tataricum* decreased over the years to an extent that significantly influenced HA fertilizer on the height growth rates. HS affected most plant metabolic processes, regardless of their source, by controlling enzymatic systems related to primary, secondary, and defense metabolisms as a reaction to environmental stress [53,54]. The results of this study are consistent with whatever metabolic pathways for humic matter affected plant growth and development, hormonal, carbon, and nitrogen metabolisms and stress response [29,50,55]. These results are quite useful, especially in the field of agronomic HS use, because soil weathering, climate change, and limited water and nutrient resources are becoming increasingly important challenges in agricultural production, and guidance for using HS is often directed at alleviating these stresses [19,53,56]. In a related study, the typical response curve showed increased HS concentration with increased plant growth solutions, followed by decrease in growth at very high concentrations [57,58].

In the present study, the treatments of $HA_{0.2}$,HA_{10}, and HA_{20} significantly increased the soil's EC, and K_2O, whereas the content of CO_2 and NO_3 was significantly reduced as compared to control. These results are consistent with previous studies on soil physicochemical properties; in particular, soil organic matter content and nutrient concentrations increased [32,50,53,59]. P_2O_5 was statistically different and increased among all the treatments. In another related study, phosphorus concentrations increased with increasing levels of humic acid regardless of the yield response [32,49,60]. The effect of phosphorus absorption was the opposite of that relating to nitrogen—absorption increasing with higher doses [61]. HA and phosphorus applications increased the growth parameter of the plants [58]. Technically, HA is not a fertilizer, even though in some studies it is described as such [7]. In some instances, the use of fertilizers could be stopped at once if there is enough organic material allowing the soil to be fully dependent on microbial processes and humus production to sustain itself [9,53,62].

5. Conclusions

Our study revealed a positive effect of oxidized brown coal humic fertilizers on tree growth even though the humic fertilizer concentrations may differ depending on the species. Planted tree growth treated with HS was compared with RHGR tests. Specifically, *A. tataricum* decreased over the years to an extent that was statistically significant for high growth rates. However, there was a variety of impacts on growth due to the adaptability of the tree species and the ecological environment. The experimental site soil, with a very high sodium content (pH of 8.23 to 8.32) and Mg, was significantly unchanged during HA fertilization treatments. Nonetheless, the increase in the assimilable K_2O, P_2O_5, and OM may have positively affected tree growth. Findings from this experiment show that the application of oxidized brown coal humic fertilizer can positively affect the RHGR of planted trees and certain adaptability traits related to it. Therefore, further studies will be needed for long-term monitoring, including those in which species of trees and soil types necessary for specific objectives in different ecological conditions.

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