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Ranking thirteen tree species based on their impact on soil physiochemical properties, soil fertility, and carbon sequestration in Northeastern China

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ABSTRACT

Site-appropriate tree species can provide greater ecological benefit by improving soil physicochemical properties and soil fertility and by increasing carbon sequestration. However, inter-species ranking derived from long-term, reliable data is still scarce. In this study, 13 tree species from >30 yr of afforestation at long-term experimental forest plots were selected, and 24 parameters comprised of soil physiochemical properties, fertility, and level of carbon sequestration were determined to rank the tree species. The two ranking methods used (significance summation method and PCA extraction method) showed similar inter-specific differences (linear relations, r^2 = 0.68–0.95, $p < 0.05$), with the exception of a weak match for C sequestration rankings (r^2 = 0.49, $p < 0.05$). *Picea*-J (*Picea jezoensis*), *Juglans*, and *Fraxinus* showed favorable effects on soil physicochemical properties, while others, such as *Quercus*, *Populus*, and *Pinus*-T, had adverse effects. In terms of soil fertility, the tree species with scores above the average were *Ulmus*, *Picea*-J, *Fraxinus*, *Pinus*-K (*Pinus koraiensis)*, and *Picea*-K (*Picea koraiensis*), while *Larix*, *Populus*, *Quercus*, and *Pinus*-T (*Pinus tabuliformis*) had scores much lower than the average. The available N, total N, total P, total K, TG, available P, available K, and EEG for the above-average group (*Juglans*, *Phellodendron*, *Fraxinus*, *Pinus*-K, *Picea*-K, *Picea*-J, *Ulmus*) were 36%, 55%, 22%, 4%, 22%, 19%, 22%, and 4% higher, respectively, than those for the below-average group (*Larix*, *Populus*, *Quercus*, *Pinus*-T). For C sequestration by both ranking methods, *Ulmus*, *Picea*-J, and *Larix* scored significantly higher than *Pinus*-T, *Quercus*, and *Betula*. Pooling all traits, Picea-J and Ulmus had peak scores while Pinus-T, Quercus and Populus had the lowest. A further redundancy ordination map representing the associations between species and soil properties as well as C sequestration also confirmed the above-mentioned findings. The entire survey showed that 44.5% afforestation with Populus species could probably increase the risk of soil physical degradation, soil fertility reduction, and lower carbon sequestration. In contrast, an increase in the percentage of the native species such as *Ulmus* and *Picea*-J, would efficiently benefit these ecological services. Our findings provide the basic data to support afforestation in China as well as for ecological functional evaluation based on species differences.

1. Introduction

Large-scale tree planting projects are becoming increasingly common in environmental conservation, in an effort to increase the resilience toward natural disasters (Wu and Wang, 2016) and to improve an urban environment (Oldfield et al., 2014). The soil is the vital foundation of terrestrial ecosystems. People depend on the soil-derived ecosystem, which regulates C storage and climate change mitigation. The soil also physically supports plant growth, supplies nutrients for the development of vegetation, conserves biodiversity, and benefits human well-being (Ren et al., 2012; Edmondson et al., 2014a, 2014b; Lorenz and Lal, 2015; Zhang et al., 2015; Lv et al., 2016; Xiao et al., 2016). Planting trees that promote soil improvement and favor related ecological services are important for sustainable afforestation (Edmondson et al., 2014b; Mchugh et al., 2015). A reliable ranking of tree species will facilitate the selection of trees for such afforestation practices. Long-term field experimental forests or common garden experiments in which several tree species are grown in the same soil site for a long duration can provide a sound criterion for evaluation of the tree species (Prescott and Grayston, 2013). In Northeastern China, urban experimental forests are in the botanical gardens and in the University experimental forests, such as the Heilongjiang Botanical Garden (Ren,

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Table 1
The basic properties of plantation forests afforested by 13 tree species and treatments during forest development.

Abbreviation	Density	Height	DBH	Cross-section	GD	Age	Plot No.	Plot in Fig. 1	Afforestation year and treatments (all plots were regular tending competing weeds and loosen soils before canopy close)
Betula	840	12.73	18.1	21.6	21.95	55.2	5	19,20,28,32,39	Planted in 1952 (1site, 3 m*3 m), 1957 (1site, 1 m*1 m),1960 (0.5 m * 1 m 1site and 1 m * 1 m 2 sites). 2-yr Seedlings 85–95% survival. One row of trees were removed in 1964 because the forest was too dense.
Pinus-T	954	11.18	21.67	35.2	28.57	56.9	6	23–27, 56	Planted in 1952, 2 m * 2 m, 2-yr seedlings, 90% survival; some trees transplanted to the campus in 1958, weak trees, thinning in 1960–1965.
Picea-K	715	11.11	20.56	23.7	27.05	61	5	43,44,45,52,53	Planted in 1952, 5-yr seedlings, 1 m * 2 m, 60% survival, with replanting in 1965 for good forest structure.
Pinus-K	1040	10.59	16.57	22.4	20.63	40.4	5	46,47,62,63, 82	Planted in 1952, 9-yr seedlings, 6 m * 2 m, 30–40% survival, thereafter replanting. In 1981 transplanting. Different aged trees mixed in this plantation today
Juglans	950	12.4	22.79	38.7	28.98	57.7	5	2,3,8,9,57	planted in 1951–1953, 2-yr seedlings, 0.75 m * 1.5 m (2 sites), 1.5 m * 1.5 m (1site), 1 m * 1 m (2 sites). 80–95% survival and replanting some sites. Susceptible to stem diseases and nowadays bad stems are found in the forest.
Phellodendron	1205	8.07	18.8	33.4	23.39	55.3	5	16,17,18,67, 90	Planted in 1952, 1-yr seedlings, 1.5 m * 1.5 m, survival 90%. Beginning growth was good but after heavy insect disease, plants died, although each year tending 1961–1965
Larix	868	13.07	19.81	26.7	25.04	48.3	11	10,21,29–31,33,61,66,70,77, 78	Planted in 1952 (2 sites, 0.75 * 1.5 m), 1954 (2 sites, 0.5 m * 1 m), 1956 (2 sites, 0.5 m * 1 m), 1959 (2 sites, 0.5 m * 1 m),1965 (2 sites, 0.5 m * 1 m),80–90% survival. 2-yr old seedlings. Tending and thinning before canopy closure, 1 row clear-cut. Underbranch-cut 8–10-yr after the initial planting.
Quercus	2690	10.35	14.4	43.8	17.59	54	5	11–15	Planted in 1959, 1-yr seedlings, 0.5 m*1 m, 90% survival, 1960 replanting. weeds-pulling out and underbranch-tending from 1962 to 1964.
Fraxinus	1035	15	21.65	38.1	25.64	57	7	1,4,5,6,7,64,65	2-yr seedlings planted in 1951 (3 sites, 80% survival, 0.5 m * 1 m), 1952 (3 sites, 90% survival, 0.5 * 1.5 m),1956 (1 site, 90% survival, 0.5 m * 1 m). Tending and thinning from 1961 to 1964, final 1.5 m * 1.5 m 6 sites, 1 site 1.5 m * 3 m.
Populus	1035	12.35	18.77	28.6	22.47	50	5	36,37,38,42, 55	2-yr seedlings planted in 1953, survival 70%-90%, 0.5 m * 1 m and 0.75 m * 0.75 m. In 1956 and 1963 thinning-cuts, final spacing 1.5 m * 3 m.
Ulmus	665	11.7	27.19	38.6	32.12	43.9	10	35,40,41,50,54,76, 83–86	2-yr old seedlings planted in 1951 to 1962, 1.5 m * 1.5 m, 0.5 m * 1.5 m and 0.75 m * 0.75 m. Two times thinning cut 5-yr and 10-yr after the planting to 1.5 m * 3 m spacing.
Pinus-S	790	12.38	24.01	35.8	29.66	51	10	22,34,48,49,51,68,69,71,75,79	Planted from 1952 to 1957, re-planted in some sites in 1960. Seedlings 2–5-yr old. Survival 50–80%, 0.75 m * 1.5 m, 1.5 m * 1.5 m, some others 6 m * 2 m (in 1967 replanting to dense the forest. Tending and thinning 10-yr old after the initial planting.
Picea-J	696	12.53	22.15	26.8	27.53	38	5	58,59,60,80, 81	Planted from 1980 to 1983. Seedlings 2–5-yr old and survival 80%, 1 m * 2 m, and regular tending with replanting in 1990s.

Note: During the forest development, some other species invaded most of the plantation forests except for the *Quercus* forest. Thus, the tree density was a sum of the dominant planted species and the trees that invaded the canopy layer (usually < 30%). Full names of the species and their abbreviations are as follows: *Pinus tabuliformis*, *Pinus*-T; *Picea koraiensis*, *Picea*-K; *Pinus koraiensis*, *Pinus*-K; *Picea jezoensis*, *Picea*-J; *Pinus sylvestris* var. *mongolica*, *Pinus*-S; *Betula platyphylla*, *Betula*; *Juglans mandshurica*, *Juglans*; *Phellodendron amurense*, *Phellodendron*; *Larix gmelinii*, *Larix*; *Quercus mongolica*, *Quercus*; *Fraxinus mandshurica*, *Fraxinus*; *Populus* spp., *Populus*; *Ulmus pumila*, *Ulmus*. Density: plant/ha; Height, m; DBH, diameter at breast height, cm; Cross-section, m^2/ha; GD, ground diameter, cm; Age, tree age, year.