

Effects of Water-Fertilizer Coupling on Tree Growth in *Pinus tabuliformis* Ecological Forests (Postprint)

Authors: Zhang Tingyu, PENG Zuodeng, Jia Suping, Jia Jianxue, Yu Lingxiao

Date: 2020-05-28T00:00:00+00:00

Abstract

Due to poor soil water and nutrient conditions in the sandy plains of Beijing, tree growth is generally sluggish following large-seedling afforestation of *Pinus tabuliformis* ecological forests. To reduce post-planting mortality and promote healthy growth of *Pinus tabuliformis* while controlling costs, this study employed a split-plot experimental design to conduct a comparative trial with three irrigation levels and three application rates of organic fertilizer derived from garden waste. The effects of irrigation and organic fertilizer application on the growth of *Pinus tabuliformis* were investigated by measuring tree height, diameter at breast height (DBH), chlorophyll content, and leaf nutrient content indicators.

The results indicate that: (1) Irrigation can significantly improve growth indicators of *Pinus tabuliformis*, including DBH, tree height, and physiological parameters; the promoting effect on tree height and DBH under moderate irrigation treatment (A2) was even greater than that under high irrigation treatment (A3). (2) One year after fertilization, fertilization had a significant effect on the growth of *Pinus tabuliformis*, but differences among the three fertilization levels were not significant. (3) One year after fertilization, no significant interaction existed between irrigation and organic fertilizer application. Fertilization and irrigation exert a significant promoting effect on the growth of *Pinus tabuliformis*. Considering both the effects of fertilization and irrigation and the comprehensive resource use efficiency, applying a small amount of organic fertilizer combined with drip irrigation at a rate of $80 \text{ L} \cdot (10 \text{ d} \cdot \text{plant} \cdot \text{time})^{-1}$ during the growing season (April–September) represents a relatively economical and effective management measure for *Pinus tabuliformis* ecological forests.

Full Text

Effect of Water-Fertilizer Coupling on the Growth of *Pinus tabulaeformis* Ecological Forest

Tingyu Zhang¹, Zuodeng Peng^{1*}, Suping Jia², Jianxue Jia², Lingxiao Yu^{2}

¹ College of Forestry, Beijing Forestry University, Beijing 100083, China

² Beijing Daxing Forestry Workstation, Beijing 102600, China

Abstract

Due to poor soil water and nutrient conditions in the sandy lands of the Beijing plain, the growth of *Pinus tabulaeformis* ecological forests established with large seedlings is generally slow. To reduce post-planting mortality while controlling costs and promoting healthy growth, this study employed a split-plot experimental design to compare three irrigation levels with three application rates of garden waste organic fertilizer. The effects of irrigation and organic fertilization on tree growth were investigated by measuring tree height, diameter at breast height (DBH), chlorophyll content, and leaf nutrient concentrations. The results showed that: (1) Irrigation significantly improved growth indicators including DBH, tree height, and physiological parameters, with the medium irrigation treatment (A2) producing even greater promotion of height and DBH than the high irrigation treatment (A3). (2) One year after fertilization, fertilizer application had significant effects on growth, but no significant differences were observed among the three fertilization levels. (3) No significant interaction between irrigation and organic fertilizer application was detected after one year. While combined fertilization and irrigation significantly promoted *P. tabulaeformis* growth, considering both treatment efficacy and resource use efficiency, applying a small amount of organic fertilizer combined with drip irrigation at 80 L per plant per 10-day interval during the growing season (April–September) represents an economical and effective management strategy for *P. tabulaeformis* ecological forests.

Keywords: *Pinus tabulaeformis*, irrigation, fertilization, tree growth

Introduction

Pinus tabulaeformis is characterized by its tolerance to low temperatures, drought, and poor soil conditions, making it one of the most widely distributed forest communities in temperate coniferous forests of northern China and a primary afforestation species in the region. Although widely used in Beijing's plain afforestation projects, large transplanting practices have led to problems including high mortality, poor growth, and severe *Dioryctria* moth infestations. Since water and nutrients exhibit interactive effects, studying water-fertilizer coupling can improve resource use efficiency in practice while holding significant ecological importance for environmental improvement.

Global fertilizer consumption increased dramatically from 30 million tons to 170 million tons between 1960 and 2008, with extensive fertilizer use—particularly chemical fertilizers—significantly elevating nitrate concentrations in soil and groundwater worldwide. Early research demonstrated strong correlations between water availability and fertilizer application rates, with Aron (1975) pioneering studies on optimal fertilization under controlled irrigation in arid regions. Numerous studies have shown that different irrigation and fertilization levels can produce synergistic, antagonistic, or additive effects on plant growth, development, and physiological ecology. Appropriate irrigation creates synergistic effects with nutrient utilization rates and fertilizer efficiency, significantly increasing nitrogen mineralization rates and plant nitrogen fixation. Conversely, proper fertilization affects soil-plant water thermodynamic functions and partial molar free energy gradients, promoting water use efficiency. For plant growth, fertilization compensates for drought stress by reducing plant water potential and increasing the driving force for deep soil water movement, thereby alleviating physiological dysfunction caused by water deficit and enhancing drought resistance. However, since fertilization significantly promotes plant growth—especially leaf area—insufficient irrigation can exacerbate water stress, suggesting that water-fertilizer interactions may involve both synergistic and antagonistic mechanisms. Establishing appropriate water and fertilizer quotas is therefore crucial for sustainable plant growth and ecological development.

Current water-fertilizer coupling research primarily focuses on three aspects: (1) plant functional trait responses to different water-fertilizer treatments, particularly photosynthesis and transpiration; (2) effects on soil fertility and mechanisms promoting nutrient absorption, transformation, and utilization to coordinate plant-soil relationships and achieve efficient nutrient use; and (3) impacts on crop product quality, quantity, and characteristics. Water-fertilizer integration technology has been widely applied in agricultural production in China, though few reports exist for forestry, particularly for large-diameter seedling cultivation and management.

Recent ecological forest fertilization research has shifted from chemical fertilizers to organic and sludge fertilizers with ecological benefits, driven by both cost and environmental considerations. While inorganic fertilizers significantly promote plant growth in the short term, they poorly ameliorate soil physical and chemical properties over time and fail to support sustained nutrient supply for large-diameter seedlings. Organic fertilizer application improves water use efficiency and provides favorable soil conditions for water conservation compared to chemical fertilizers, while appropriate irrigation levels reduce soil nutrient loss. For urban ecological forests, organic fertilizer produced from composted garden waste represents an economical, effective, and readily available resource, yet relevant application research remains scarce, particularly regarding the coupled effects of irrigation and organic fertilization on large *P. tabuliformis* seedlings after planting. This study aims to investigate the effects of different water-fertilizer combination treatments on morphological and physiological indicators of *P. tabuliformis* ecological forests in Beijing's plain sandy lands, providing

valuable scientific evidence for economical and effective ecological forest management strategies.

1. Site Description

The experimental site is located along the Yongding River in Daxing District, Beijing (116°14 19.88 E, 39°36 47.01 N), characterized by a warm temperate semi-humid continental monsoon climate with an average annual temperature of 12 °C and average annual precipitation of 556 mm.

The soil is sandy with a pH of 8.8, organic matter content of 4.95 g · kg⁻¹, total nitrogen of 0.39 g · kg⁻¹, available phosphorus of 13.1 mg · kg⁻¹, available potassium of 11.78 mg · kg⁻¹, and alkali-hydrolyzable nitrogen of 59.32 mg · kg⁻¹. The volumetric water content is 26.5%, total porosity 54.1%, bulk density 1.25 g · cm⁻³, and saturated water content 39.19%. According to Beijing's soil nutrient evaluation standards, all indicators except available phosphorus are low. The soil exhibits weak stratification, good permeability, and poor water and nutrient retention, with deficiencies in nitrogen, phosphorus, and potassium. The shallow groundwater table ranges from 8–10 m, making irrigation the primary water source for plant growth.

2. Materials and Methods

2.1 Experimental Materials The study subjects were large *P. tabuliformis* seedlings planted in Daxing District. The organic fertilizer, produced by the Beijing Academy of Forestry and Landscape Architecture, was derived from composted garden waste containing 52% organic matter, 6% total nutrients, 5% moisture, and pH 7.5. Irrigation water was sourced from groundwater.

The *P. tabuliformis* seedlings were planted in 2013 at 4 m × 5 m spacing in east-west rows. No pruning was performed during 2016–2017. By late 2016, the average DBH was approximately 6.62 cm and average crown width 2.5 m. The experimental plantation exhibited minor *Dioryctria* moth infestations but relatively uniform growth.

2.2 Experimental Design A split-plot design was employed with irrigation amount (A) as the main plot treatment and fertilization amount (B) as the subplot treatment. Irrigation treatments consisted of 40 L · (10 d · plant · time)⁻¹ (A1), 80 L · (10 d · plant · time)⁻¹ (A2), and 120 L · (10 d · plant · time)⁻¹ (A3). Fertilization treatments were 5 kg · plant⁻¹ (B1), 15 kg · plant⁻¹ (B2), and 25 kg · plant⁻¹ (B3), with a blank control receiving neither fertilization nor drip irrigation. The experiment included three replications, with no fewer than 20 trees per treatment.

Fertilization was applied in early March via ring application at 1.2 m from trees and 20 cm depth. Irrigation was conducted via drip irrigation during the growing season (March-September) at 10-day intervals with per-plant water amounts of 40, 80, or 120 L (hereafter referred to as low, medium, and high water treatments). Drip irrigation system installation and testing were completed by late March 2017.

2.3 Measurement Indicators 2.3.1 Morphological Indicators

Initial measurements were completed in February 2017, with final measurements in late 2018. Growth indicators included tree height, DBH, crown width, new branch length, and shoot length. Tree height was measured using a laser rangefinder, while DBH measurement positions were marked with paint during the first survey to ensure consistency. New branch length was measured as current-year growth of primary branches in four cardinal directions, with the second measurement representing the second-year growth of the same branches.

2.3.2 Chlorophyll Content

Leaf chlorophyll was extracted by soaking 0.2 g of leaf material in 20 mL of mixed solution (80% acetone and 95% ethanol at 1:1 ratio). Absorbance values at 663 nm, 646 nm, and 470 nm were measured to calculate chlorophyll a, chlorophyll b, and carotenoid contents.

2.3.3 Leaf Nutrient Content

Total nitrogen content was determined using the automatic Kjeldahl method, total potassium by flame photometry, and total phosphorus by molybdenum-antimony colorimetry.

2.4 Data Processing and Analysis All data were analyzed using SPSS 16 and Microsoft Office Excel. Significance was tested using ANOVA ($P < 0.05$), with multiple comparisons performed using Duncan's new multiple range test.

3. Results

3.1 Effects of Water-Fertilizer Treatments on *P. tabuliformis* Growth

Table 2 shows that both fertilization and irrigation significantly promoted height, DBH, and new branch length growth, with a significant interaction effect for height but not for DBH or new branch length.

For tree height, DBH, and new branch length, all treatment groups showed significant differences compared to the control. Under low irrigation, height increments were small across all fertilization levels. Medium irrigation (A2) produced greater increments than low irrigation (A1), but high irrigation (A3) showed no significant difference from medium irrigation (A2). Among fertilization levels, medium (B2) and high (B3) rates showed no significant differences, while low

fertilization (B1) produced the highest growth rate. Irrigation-fertilization effects on DBH were similar to those on height, with medium irrigation (A2) producing the highest growth rate and no significant difference between high (A3) and low (A1) irrigation. Medium fertilization (B2) most significantly promoted DBH growth rate, with no significant difference between high (B3) and low (B1) fertilization.

For new branch length growth rate, high irrigation (A3) produced the highest rates across all fertilization levels, with medium irrigation (A2) exceeding low irrigation (A1). Under high irrigation, medium fertilization (A3B2) yielded the highest growth rate, while under low and medium irrigation, low fertilization (A1B1, A2B1) produced the highest rates.

[Figure 1: see original paper]

3.2 Effects of Water-Fertilizer Treatments on Leaf Chlorophyll Content The control group showed significantly lower chlorophyll a, chlorophyll b, and carotenoid contents than all treatment groups, with no significant interaction effects (chlorophyll a/b: $P = 0.974$). All treatment indicators were significantly higher than the control, though differences among treatments were not significant.

Chlorophyll a and carotenoid contents were slightly higher under medium irrigation (A2) than low irrigation (A1), but showed minimal improvement under high irrigation (A3) compared to medium irrigation (A2). All treatments had higher chlorophyll b content than the control, though not significantly different. The chlorophyll a/b ratio showed highly significant differences between treatments and control, with medium irrigation (A2) producing higher values.

[Figure 2: see original paper]

3.3 Effects of Water-Fertilizer Treatments on Leaf Nutrient Content The control group differed significantly from treatment groups in leaf nutrient content, with no significant interaction effects. Garden organic fertilizer affected different nutrient components variably. While total nitrogen and potassium contents showed no significant differences among treatments, all treatment results were significantly higher than the control. Different fertilization levels showed no significant effects on leaf total N and K contents, and the three irrigation levels under each fertilization level showed no significant differences in leaf total N. Medium irrigation with medium fertilization (A2B2) demonstrated better promotion effects, while low fertilization (B1) showed the poorest promotion of leaf total P. Overall, low irrigation with medium fertilization (A1B2) performed well. The N/P ratio in leaves decreased after water-fertilizer treatment, showing significant differences from the control. No significant differences in the ratio were found among the three fertilization levels ($P = 0.102$), but significant differences existed among irrigation levels ($P = 0.009$).

[Figure 3: see original paper]

4. Discussion

4.1 Effects on Morphological Growth Fertilization results indicated that high and medium rates did not significantly improve *P. tabuliformis* growth rates, though organic fertilizer and irrigation significantly promoted surrounding soil nutrient content. This may be attributed to the short experimental duration and slow growth rate of *P. tabuliformis*, resulting in no significant differences among fertilization levels within one year. Additionally, the high soil pH of 8.8 likely limited nutrient availability to the trees, preventing highly significant growth promotion even with fertilization.

Analysis of growth and physiological indicators revealed significant promotion under high or medium irrigation, though differences between these treatments were not significant. Both height and DBH results showed lower values under high irrigation than medium irrigation. This may be partly explained by pH reduction through irrigation, as high irrigation decreased soil alkalinity, facilitating nutrient absorption and promoting growth. However, monitoring revealed limited pH reduction under water-fertilizer treatments, only partially alleviating pH inhibition of nutrient uptake. The lack of significant difference between medium and high irrigation may also result from the sandy soil's poor water retention, causing rapid infiltration. While irrigation effectively improved water conditions and significantly enhanced growth, *P. tabuliformis* has relatively low minimum ecological water requirements, making high irrigation unnecessary for optimal growth increments. Thus, under the three fertilization levels tested, medium irrigation adequately supplied growth requirements, with the primary need being reduction of soil pH in *P. tabuliformis* stands.

Han and Dong (2019) found that spraying humic acid-containing water-soluble fertilizer on *P. tabuliformis* improved disease resistance (reducing incidence by 6.5 percentage points) and significantly promoted growth, consistent with our findings that fertilization and irrigation significantly enhance morphological indicators.

4.2 Effects on Leaf Physiological Indicators Wang et al. (2018) reported that under low water stress, increased fertilization benefits photoreactions. Our study found that under low irrigation, increased fertilization raised leaf chlorophyll content, with low-irrigation high-fertilization treatments showing higher chlorophyll a and b contents than low-irrigation low-fertilization treatments, consistent with these findings.

Liu et al. (2013) studied chlorophyll content changes in *Lespedeza* under water-fertilizer regulation, finding that chlorophyll content continuously increased with irrigation and phosphorus application but initially increased then decreased with nitrogen application. Our results indicate that excessive irrigation does not significantly promote chlorophyll content, likely because high soil moisture causes

nutrient translocation, preventing further increases in available nutrient concentration around roots despite increased water. Liu' s study was conducted in northwestern sandy lands where irrigation did not reach this threshold.

4.3 Leaf Nutrient Content Water-fertilizer management can alter plant nutrient content, promoting increases in some nutrients while decreasing others. Leaf nutrient stoichiometry reflects plant nutrient utilization strategies and relationships among nutrients. Wu (2014) investigated effects of water-fertilizer integration on jujube leaf nutrients. Our study found that the N/P ratio in *P. tabuliformis* leaves after water-fertilizer treatment was significantly lower than in the control, contrasting with Wu' s results. An N/P ratio below 14 indicates nitrogen limitation, suggesting that nitrogen inhibition of *P. tabuliformis* growth intensified after treatment. This implies that future fertilization in this region should supplement nitrogen when applying organic fertilizer or use organic fertilizers with higher nitrogen content.

Overall, while water-fertilizer interactions were not significant after one year, treatments did enhance plant growth and physiological indicators. Considering resource use efficiency, we recommend applying small amounts of organic fertilizer combined with drip irrigation at 80 L per plant per 10-day interval during the growing season (April-September) as an economical and effective management strategy for *P. tabuliformis* ecological forests.

References

- ARNON I, 1975. Physiological principles of dry and crop production [A]. In: Gupta US. Physiological Aspects of Dryland Farming[C]. N Y: University Press: 3-124.
- BARRACLOUGH PB, 1989. Root growth, macro-nutrient uptake dynamics and soil fertility requirements of a high-yielding winter oilseed rape crop[J]. Plant Soil, 119(1).
- CHEN PP, YANG QQ, HOU JB, et al., 2019. Exploring the effect of water and fertilizer regulation on the growth of *Robinia pseudoacacia* plantation[J]. Agric Technol, 39(09): 84-86.
- GAO P, JIAN HZ, WEI X, et al., 2012. Application status and development prospect of water fertilizer integration technology [J]. Mod Agric Sci Technol, 8: 250.
- HAN PY, DONG WX, 2019. Effect of humic acid containing water-soluble fertilizer on the growth of *Pinus tabulaeformis* [J]. Bull Agric Sci Technol, (11): 111-112.
- HAN SJ, LU GY, JIANG MM, et al., 2010. Effect of water phosphorus coupling on NPK content of sugarcane leaves [J]. Guangxi Agric Sci, 41(9): 938-942.

- HE JS, HAN XG, 2010. Ecological chemometrics: Exploring the theory of unity from individual to ecosystem[J]. *J Plant Ecol*, 34(1): 2-6.
- JONES J W, HOOGENBOOM G, PORTER CH, et al., 2003. The DSSAT cropping system model[J]. *Eur J Agron*, 18: 235-265.
- KOERSELMAN W, 1996. The vegetation N : P ratio: A new tool to detect the nature of nutrient limitation[J]. *J Appl Ecol*, 33: 1441-1445.
- LI YD, WU L, ZHANG ZD, WEN LK, 1997. Effects of N, NP, NPK fertilizer application on the growth, yield and leaf element content of bilberry[J]. *Jilin Agric Sci*, (3): 69-72.
- LIANG YJ, XU GB, XIE XH, et al., 2011. Effect of water and fertilizer treatment on soil pH value of pepper protected land[J]. *Prog Water Conserv Hydrop Sci Technol*, 31(2): 50-52.
- LIU MZ, CHEN ZL, TANG FD, 2013. Effect of water and fertilizer regulation on chlorophyll content of *Lespedeza* in Northwest Liaoning sandy land[J]. *Liaoning For Sci Technol*, (3): 1-2.
- LIU SM, SUN CZ, SUN BY, 2004. Study on suitable irrigation quota of *Pinus tabulaeformis* and *Platyclusus orientalis* plantation[J]. *For Sci*, 6: 85-90.
- MARINOV I, MARINOV AM, 1999. A coupled mathematical model to predict the influence of nitrogen mohamed AR A[J]. *Nitrogen Accumulation Seed yield Water Use Three*, (20): 1-3.
- NATIONAL SOIL CENSUS OFFICE, 1998. Chinese soil [M]. Beijing: China Agricultural Press: 356.
- PRAEHTJE, NIEKELL CD, HARPER JE, et al., 1994. Agronomic evaluation of no-nodulating and hypemodulating mutants of soybean[J]. *Crop Sci*, 34(3): 738-739.
- SHANG FZ, REN SM, YANG PL, et al., 2016. Effects of different irrigation water types, N fertilizer types, and soil moisture contents on N O emissions and N fertilizer transformations in soils[J]. *Water Air Soil Pollut*, 227: 225.
- SONG XC, QIU MH, GUO DJ, et al., 2019. Effects of water and fertilizer treatment on growth, water use efficiency and photosynthetic characteristics of watermelon cultivated in substrate [J]. *Soil*, 51(2): 284-289.
- SUN XY, 2004. *Pedology*[M]. Beijing: China Forestry Press: 217.
- WANG C, JIA BQ, JIA GF, et al., 2017. Study on the effect and development strategy of afforestation in Beijing plain[J]. *Urban For Chin*, 15(6): 6-11.
- WANG HB, CAO HX, HAO SX, et al., 2018. Effect of water and fertilizer coupling on growth and chlorophyll fluorescence parameters of greenhouse tomato[J]. *J Drain Irrig Mech Eng*, 36(10): 1047-1052.

WANG P, WAN P, 2018. Growth regularity of *Pinus tabulaeformis* plantation in the xiaolongshan mountain[J]. J NW For Univ, 33(4): 100-104.

WANG SQ, LI X, XU FA, et al., 2001. Effects of long-term application of chemical fertilizer and organic fertilizer on physical properties of tidal soil[J]. Chin J Ecol Agric, 2: 81-82.

WANG XL, 2019. Physiological basis of density and organic fertilizer to improve water use efficiency of film mulched spring maize[D]. Graduate School of Chinese Academy of Sciences (Research Center for Soil and Water Conservation and Ecological Environment of Ministry of Education).

WU HL, 2014. The effect of water and fertilizer integration on the nutrient dynamics, quality and yield of jujube leaves[D]. Yangling: Northwest Agricultural and Forestry University of Science and Technology.

YADAV RS, SHARWAR I, PANDEY UK, et al., 1998. Effect of various water potential treatment on nitrate reductase activity in wheat genotypes[J]. Agric Sci Dig, 18(2): 72-79.

YANG SH, XIAO YA, XU IZ, 2018. Organic fertilizer application increases the soil respiration and net ecosystem carbon dioxide absorption of paddy fields under water-saving irrigation[J]. Environ Sci Pollut Res, 25: 9958-9968.

YU YH, WANG Y, ZHONG XP, 2019. Current situation and prospect of water and fertilizer coupling research in plantation[J]. World For Res, 32(2): 35-39.

ZHANG BJ, GUO SS, LI JQ, et al., 2015. Effects of soil mixing and fertilization on physical and chemical properties of iron tailings matrix and growth of *Pinus tabulaeformis* and *Pinus sylvestris* seedlings[J]. For Sci, 51(5): 12-20.

ZHANG LX, BAI YF, HAN XG, 2003. Application of N: P stoichiometry to ecology studies[J]. Acta Bot Sin, 45(9): 1009-1018.

ZHOU HL, HUANG SM, 2017. The effect of sink source relationship on chlorophyll content and chlorophyll a/b value of rice[J]. Green Technol, 24: 147-149.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv –Machine translation. Verify with original.