Analysis of factors influencing the calibration of the Root Bundle Model (RBM): the case study of the Hyrcanian forests (Iran)

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1. Introduction

- Root reinforcement is the most effective factor to stabilize slopes. The quantification of root reinforcement is fundamental for the development of bioengineering techniques and the improvement of protection forest management.

2. Research Objectives

- Which is the main factor influencing mechanical properties of roots?
- Quantifying root mechanical properties
- Calibrating Root Bundle Model (RBM)

3. Study area

- The experimental field is located in the Kheyrud forest, within **Hyrcanian forest**, **Northern Iran** (Figure 1).
- Lat. 36° 33' 41" to 36° 33' 51" N
- Long. 50° 33' 14" to 103 50° 33' 28"
- Mean annual precipitation is **1300 mm**
- The heaviest precipitation in **fall**
- The wettest month: **October**
- The driest month: **August**
- The coldest: **February**
- The warmest month: **August**
- study sites:

Patom (Figure 2): 400 m a.s.l
Namkhane (Figure 3): 900 m a.s.l
Chelir (Figure 4): 1300 m a.s.l

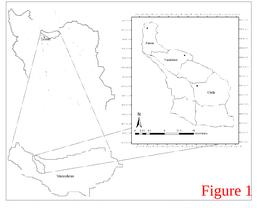


Figure 1

Figure 2
The highest mean temperature and the driest site

Figure 3
The wettest site

Figure 4
The coldest site

4. Sampling design

- Sampling roots (**16200 sample roots**) was taken at three sites for two different species with three DBH classes at up and down sides of the tree stem.

3 study sites — **Chelir, Namkhane, Patom**

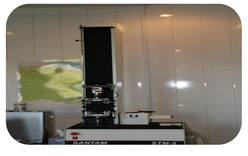
× 3 DBH classes — **<32.5, 32.5-57.5, >57.5 cm small, medium, large**

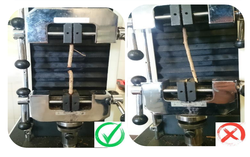
× 2 species — ***Fagus orientalis, Carpinus betulus***

× Tree side — **Up side and down side**

× 5 replicates

Sampling roots from up and down side → **Spry 15% alcohol on roots** → **Preserve roots in refrigerator for 10 days** → **Transfer roots to laboratory** → **Tensile test was done** → **Rupture must occur from middle part of the roots**





5. Calibrating model

$$F_{max}(\phi) = F_0 \phi^{\alpha}$$

Fmax: maximum tensile force (N)
Φ: root diameter (m), F0: constant
α: an exponent.

$$C(\phi) = \frac{1}{2}\left[1 + erf\left(\frac{\phi_i - \phi_m}{\phi_{sd}\sqrt{2}}\right)\right]$$

ϕm and ϕsd: coefficients relate to the mean and standard deviation

$$k(\phi_i) = k_0 + k_i \cdot \phi_i$$

k (ϕi): spring constant (N/m)
Φi: root diameter (m),
k0,i: constant parameters

$$S(\Delta x^*) = \exp\left[-\left(\frac{\Delta x^*}{\lambda^*}\right)^{\omega}\right]$$

Δx*: normalized displacement
ω: Weibull shape factor
λ*: scaling factor

$$\Delta x^*(\phi) = \frac{\Delta x}{\Delta x^{fit}_{max}(\phi)}$$

Normalized displacement

6. Results

Summary of ANCOVA and effect of different factors on tensile force as a function of root diameter such as species, up-down side, DBH classes in Chelir, Namkhane, and Patom sites.

Source	Chelir site df	Sum Square	Mean Square	F value	P value	Namkhane site Sum Square	Mean Square	F value	P value	Patom site Sum Square	Mean Square	F value	P value
Species	1	58.1	58.1	2055.3	<2e-16 ***	2.0	2.0	35.7	2.42e-09 ***	19.3	19.3	521.5	< 2e-16 ***
Up-down side	1	2.7	2.7	96.5	<2e-16 ***	0.6	0.6	10.2	0.00141 **	5.0	5.0	133.8	< 2e-16 ***
log10 (DBH)	1	15.4	15.4	545.2	<2e-16 ***	18.5	18.5	332.8	<2e-16 ***	9.2	9.2	248.0	< 2e-16 ***
log10 (Root diameter)	1	1073.3	1073.3	37950.1	<2e-16 ***	941.6	941.6	16967.6	<2e-16 ***	966.1	966.1	26116.5	< 2e-16 ***
Species*up-down side	1	2.1	2.1	73.1	<2e-16 ***	1.0	1.0	18.7	1.54e-05 ***	1.4	1.4	38.7	5.31e-10 ***

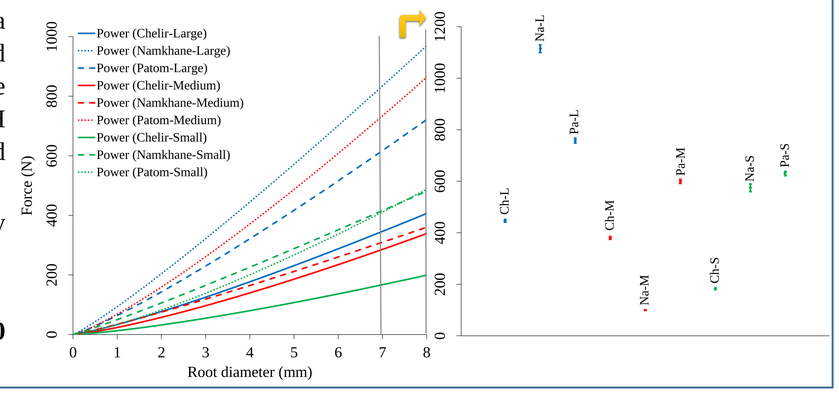
Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Lines show power-law regression curves fitted to the data. Ch, Na, Pa stands for Chelir, Namkhane, and Patom, respectively. L, M, S denote for large, medium and small DBH classes. Standard error was applied for the last root diameter class.

Tensile force rise slightly by increasing root diameter.

***Each line consist of data from 900 sample roots.**

Carpinus betulus

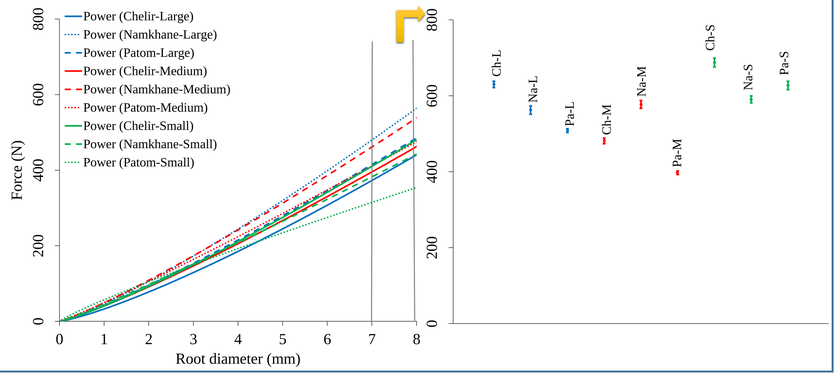


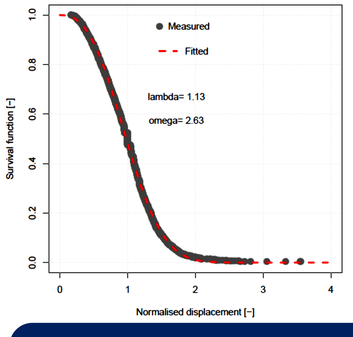
Lines show power-law regression curves fitted to the data. Ch, Na, Pa stands for Chelir, Namkhane, and Patom, respectively. L, M, S denote for large, medium and small DBH classes, respectively. Standard error was applied for the last root diameter class.

Tensile force grow gently by increasing root diameter.

***Each line consists of data from 900 sample roots.**

Fagus orientalis





The adjacent plot shows the results of the calibrated **survival function** for *Carpinus betulus* at Chelir site as a sample, where lambada is the scaling factor and omega is the shape factor.

7. Conclusions

- The variability influence by different factors for *Fagus orientalis* is lower than *Carpinus betulus*
- All the factors do not influence *Fagus orientalis*, however, the main factors impact *Capinus betulus* are DBH and region
- Overall difference in mechanical properties for same species were measured which *Carpinus betulus* showed more resistance