Impact of Thinning Levels on Cone Production in Natural Stands of Scots Pine (*Pinus sylvestris* L.)

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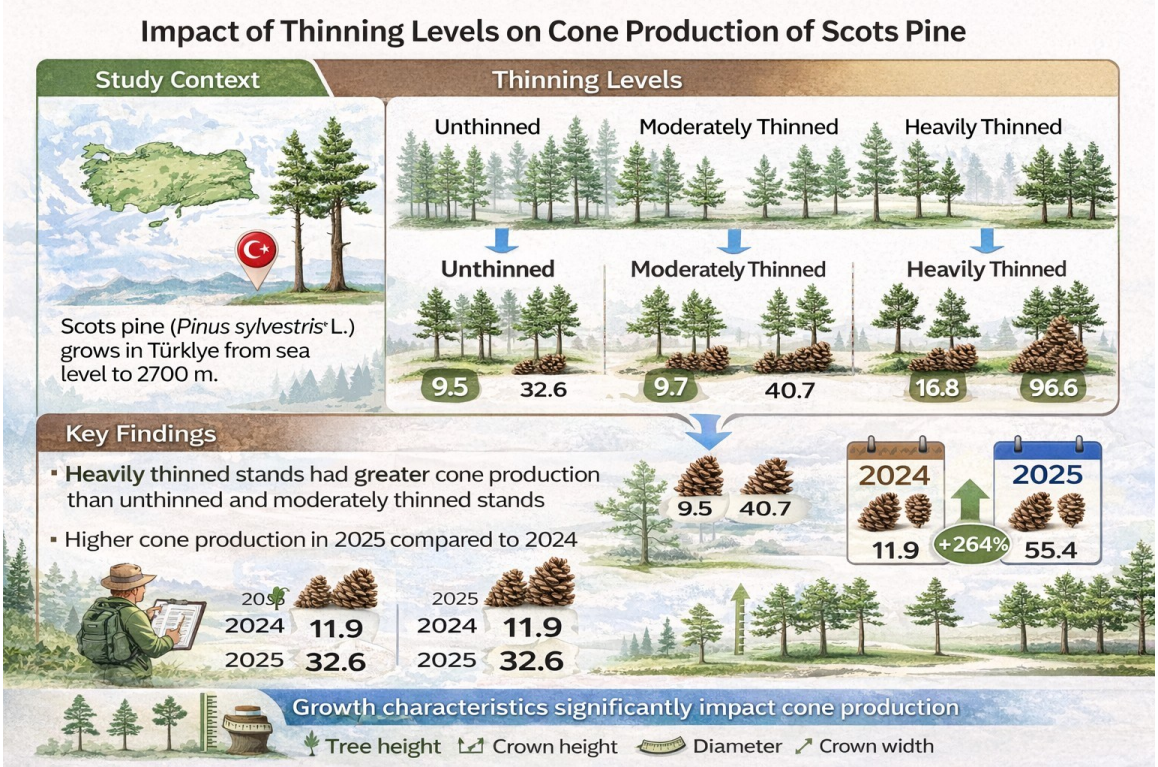
GRAPHICAL ABSTRACT



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Scots pine (*Pinus sylvestris* L.) grows from sea level up to 2700 m as small groups or individually in Türkiye. Cone and seed production is the main tool in sustainability of forest tree species. However, many biotic and abiotic factors such as stand structure and forestry practices could impact production. The impact of thinning levels (unthinned or known control, moderately thinned, and heavily thinned in 2021) together with growth characteristics on mature cone production was examined based on two-year cone data (2024 and 2025) in natural stands. Stands and individuals within stands were evaluated for both cone production and growth. Heavily thinned stands had higher cone production for both years (16.8 and 96.6) than moderately thinned (9.7 and 40.7) and unthinned (9.5 and 32.6). The year 2025 produced more abundant cones (55.4) than 2024 (11.9). Significant ($p < 0.05$) differences were found with respect to thinning level for growth characteristics and cone productions except for tree and crown heights. Years showed significant ($p < 0.05$) differences among grades and within grade for cone productions. Additionally, growth characteristics had generally significant ($p < 0.05$) impact on cone production in both grade and years.

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Keywords: Forestry; Growth; Population; Reproductive; Tending; Variation

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INTRODUCTION

Scots pine (*Pinus sylvestris* L.) is one of the most important forest tree species in Europe and Asia. It is also an exotic species in various countries such as Korea, China, Mexico, and New Zealand (Boratyński 1991). Turkish Scots pine (*Pinus sylvestris* ssp. hamata), which is one of five sub-species, is an important tree species in 23.36 million ha of Turkish forest area and by 1.41 million ha natural distribution, according to the latest forestry inventory (OGM 2025). It is classified as one of the economically and ecologically important tree species for Turkish forestry and for "National Tree Breeding and Seed Production Programme" (Koski and Antola 1993). It grows up to 45 m height, 2.0 m diameter and can be found between sea level and 2700 m, sometimes up to 3125 m at different environmental conditions (Anşin and Özkan 1996).

Various climatic conditions affect reproductivity of the species, which affects its sustainability. Scots pine is wind-pollinated and has both male and female cones on the same tree. Female cones develop approximately after 15 years on solitary trees or 25 to 30 years. Abundant male cones appear some years later (Mátyás *et al*. 2004). The female cones convert to mature cones in two years after fertilization.

A good seed year occurs every two years in Scots pine (Saatçioğlu 1976). However, there could be many biotic (*i.e*., Eriksson *et al*. 1973; Hedegart 1976; Odabaşı 1990; Kang *et al.* 2003; Zobel and Talbert 2003; Bilir *et al.* 2008, 2023, 2025; Yazıcı and Bilir 2023) and abiotic (*i.e*., Boydak 1977; Odabaşı 1990; Zobel and Talbert 2003; Bilir and Yazıcı 2024) factors that affect reproductive characteristics in forest tree species (*i.e*., Eriksson *et al*. 1973; Hedegart 1976; Boydak 1977; Odabaşı 1990; Kang *et al.* 2003; Zobel and Talbert 2003; Bilir *et al.* 2008, 2023, 2025; Yazıcı and Bilir 2023; Bilir and Yazıcı 2024).

Reproductive traits of plant species and their populations are not easily changed. It is known that common forest tending practices included thinning are mainly focused on increasing the amounts of wood products. Thinning, which has become an established forestry practice, could also have different impacts on reproductive traits. However, while the impact of some biotic and abiotic factors on cone production were investigated in Scots pine (*i.e*., Jonsson *et al.* 1976; Boydak 1977; Nikkanen and Velling 1987; Kang *et al.* 2003; Bilir *et al.* 2008), there has been a need for study on the impact of thinning grades relative to cone production. Cone production is one of the main tools for both sustainable forestry, and cones are used in various industries (Hendek Ertop and İncemehmetoğlu 2021).

This study was carried out to estimate whether forest thinning levels (unthinned, moderately thinned, and heavily thinned) have an impact on cone production, and to estimate relations among growth characteristics and cone production in natural stands of *P. sylvestris* to contribute to silvicultural and other forestry practices of the species.

EXPERIMENTAL

Materials

Study area

Studied areas/grades were selected to be close to each other (~150 m.) at similar conditions to minimize impacts of other changeable factors such as altitude, climatic, and edaphic. Trees were sampled from natural stands that were either unthinned (UT, also known control), moderately thinned (MT), and heavily thinned (HT) of the species (Fig. 1). The vertical stand profiles of the areas depending on size and position of tree crowns during data collection are shown in Fig. 1. These were drawn using TreeDraw (Staupendahl 2003). The following data were collected from 300 m^2 (30 ×10 m) plot size of each grade (Fig. 2). The thinning was practiced in the areas in year 2021. Additionally, a regional good/rich seed year was 2023. Some details of the areas are given in Table 1.

Table 1. Some Details and Number of Trees of the Sampled Areas

Grades	Latitude	Longitude	Altitude	Aspect	Age	N[a]
	(N)	(E)	(m)		(year)	
UT	521015	4492349	1841	SW	64	42
MT	521148	4492353	1831	SW	65	36
HT	521068	4492500	1863	SW	67	36

[a]Number of sampled trees of the areas.

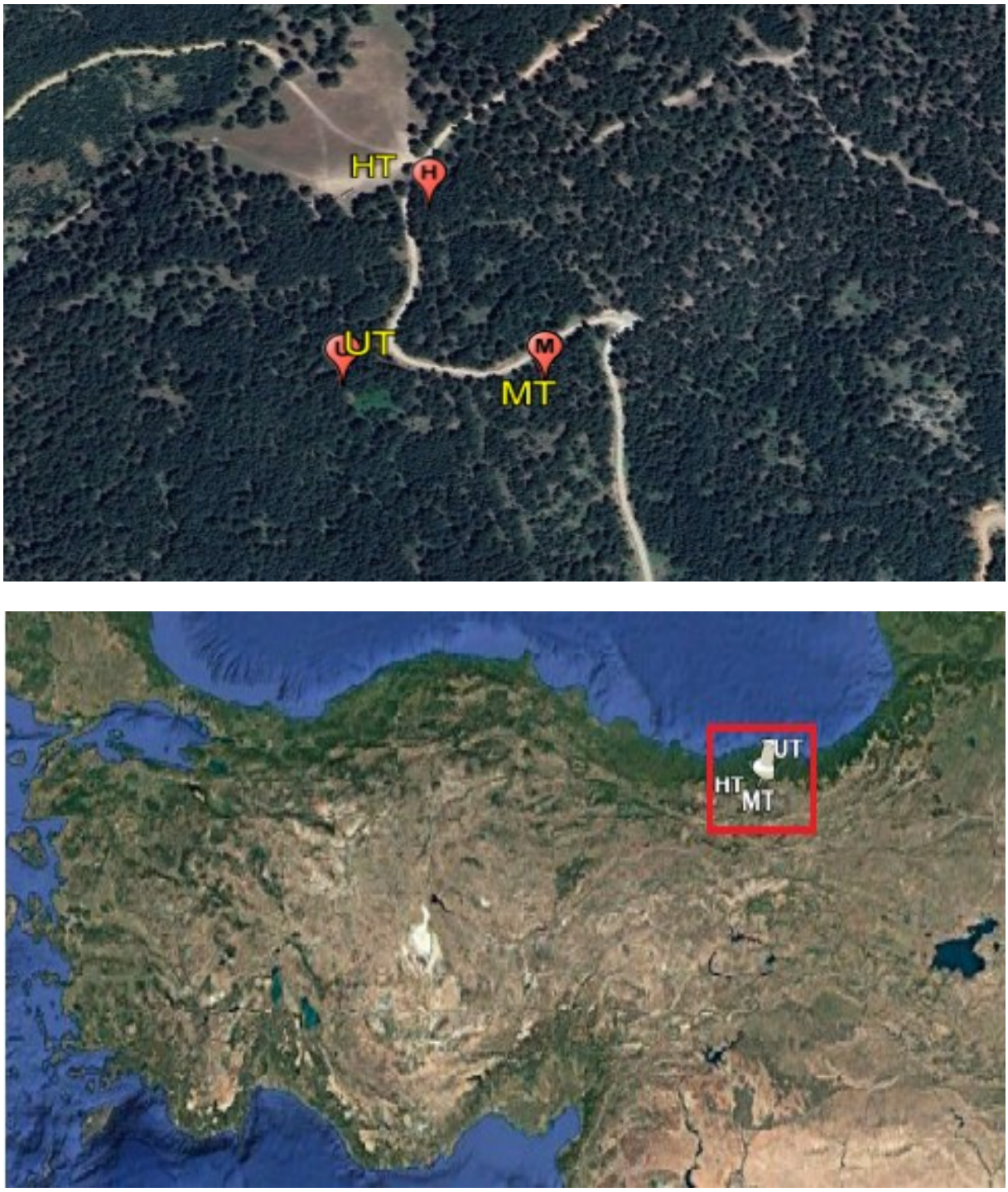


Fig. 1. Location of the sampled areas using Google Earth

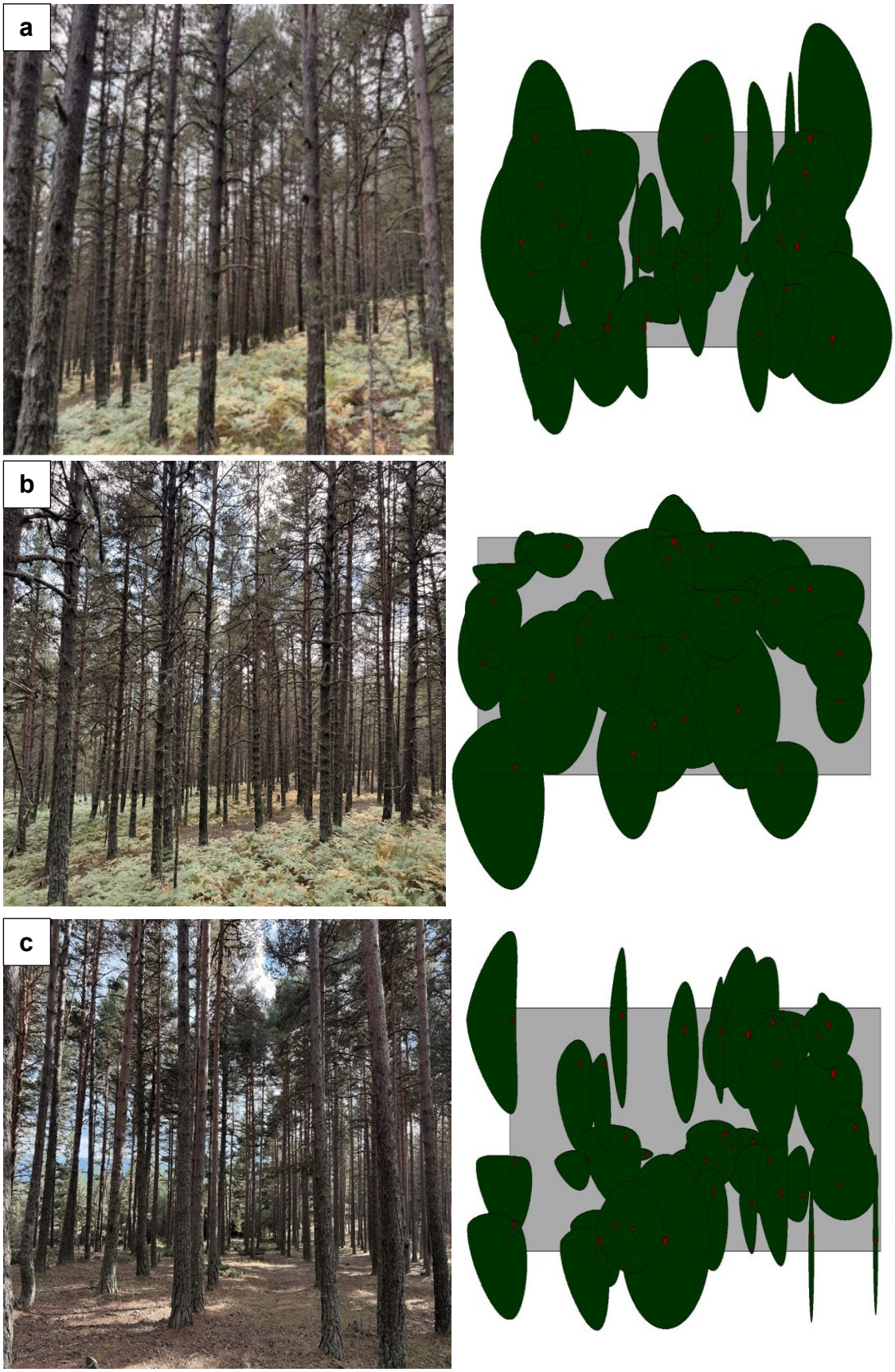


Fig. 2. Sampled areas and vertical stand profiles of (a) UT, (b) MT, (c) HT

Methods

Data collection and analysis

Tree height (H), diameter at base (D_0), diameter at breast height (DBH), crown height (CH), and crown diameter (CD) in year 2025, and number of mature cones for years 2024 and 2025 (CN-24 and CN-25) (Fig. 3) on marked areas were measured at each sampled stand.

Fig. 3. Mature cones of the species

The grades were compared for the characteristics by following linear model of analysis of variance to at SPSS (SPSS 2011) as,

$$Y_{ij} = \mu + P_j + e_{ij} \quad (1)$$

where Y_{ij} is the observation from the j^{th} tree of the i^{th} grade, μ is overall mean, P_i is the random effect of the i^{th} species, and e_{ij} is random error.

Phenotypic relations (r_p) among the characteristics were estimated in the grades as (Falconer 1989),

$$r_p = \frac{COV_{f(x,y)}}{\sqrt{\sigma^2_{f(x)}}\sqrt{\sigma^2_{f(y)}}} \quad (2)$$

where $COV_{f(xy)}$ is the phenotypic covariance between the characteristics x and y, and $\sigma^2_{f(x)}$ and $\sigma^2_{f(y)}$ are the phenotypic variances for characteristics x and y, respectively.

RESULTS AND DISCUSSION

Characteristics and Variation

Stands (with different levels of thinning) and individuals within stands showed large differences for the characteristics (Table 2). Trees in heavily thinned (HT) stands had higher cone production for both years (16.8 and 96.6) than UT (9.5 and 32.6) and MT (9.7 and 40.7) (Table 2, Fig. 4).

There could be many biotic (*i.e*., crown closure, genetic structure, growth characteristics population) (*i.e*., Eriksson *et al*. 1973; Kang *et al*. 2003; Bilir *et al*. 2006; Yazıcı and Bilir 2023; Bilir and Yazıcı 2024) and abiotic (*i.e*., altitude, climate, edaphic, year) (*i.e*., Boydak 1977; Bila and Lindgren 1998; Bilir *et al*. 2005) factors that may account for the difference. However, the present study focused on the impact of thinning levels. For instance, the number of trees per hectare was 200 lower in MT and HT than UT in the present study. Average cone number was 53 in three seed orchards of Scots pine (Bilir *et al*. 2008), while it changed among orchards and within orchard. The thinning was related to crown closure and tree density. The impact of crown closure on cone production of Taurus cedar (*Cedrus libani* A. Rich) was found by Yazıcı and Bilir (2023). Additionally, HT was different than others for cone productions for both years according to Duncan's multiple range test (Table 2).

The year 2025 produced more abundant cones (55.4) than year-24 (11.9). Annual variations of seed production were also reported in the species (Boydak 1977; Prescher *et al*. 2005). Coefficients of variations (CV < 58%) varied for the years for cone productions (Table 2). But the variations were at acceptable level for natural populations (CV < 140%) (Kang *et al*. 2023). The results indicated importance of both thinning and years on cone production and forestry practices (*i.e.*, natural regeneration, higher gene diversity in seed crop).

As is apparent in Table 2, there were also large differences among individual trees within stands. Similar variations were also estimated in clonal seed orchards of Scots pine (Bilir *et al*. 2008). For instance, cone production ranged from 25 to 146 in 2025 of HT (Table 2). The importance of year on reproductive characteristics was also indicated by Prescher *et al*. (2005). There were significant ($p < 0.05$) differences among grades/areas for growth characteristics and cone productions except of H and CH according to results of analysis of variance (Table 3).

Years indicated significant ($p < 0.05$) differences among stands for cone productions in the species. The result well accordance with occurring good seed year, depending on silvicultural characteristics of Scots pine (Saatçioğlu 1976). The cumulative contributions of trees to the overall fertility estimates for years 2024 and 2025 are shown in Fig. 5. It could be seen that abundant cone year (~ seed) was much closer to equal contribution (Fig. 5). The result was generally in accordance with coefficients of variations of cone production (Table 2).

Table 2. Averages ($\bar{x}$), Ranges and Coefficients of Variations (CV%) for the Characteristics of the Grades

Characteristics	UT**			MT			HT		
	$\bar{x}$*	ranges	CV%	$\bar{x}$	ranges	CV%	$\bar{x}$	ranges	CV %
H (m)	18.1	9.8-23.4	23.7	18.3	10.2-24.8	25.8	18.5	10.2-22.6	21.2
D_0 (cm)	33.9^{b}	20.6-47.4	21.7	29.9^{a}	16.0-41.8	23.3	36.7^{b}	23.8-47.8	15.5
DBH (cm)	26.2^{b}	15.6-41.8	24.9	23.1^{a}	11.0-32.6	25.3	28.0^{a}	16.4-44.2	18.6
CH (m)	8.8	1.2-17.1	46.1	8.5	1.2-13.8	50.8	8.4	1.6-12.4	39.5
CD (m)	4.7^{b}	1.4-8.7	42.8	4.2^{ab}	1.5-7.35	37.7	3.7^{a}	1.3-7.2	36.7
CN-24	9.5^{a}	3-19	52.4	9.7^{a}	4-19	43.9	16.8^{b}	4-41	57.5
CN-25	32.6^{a}	9-62	41.4	40.7^{a}	7-89	50.1	96.6^{b}	25-146	26.8

*The same letters showed not significantly different at $p > 0.05$ among grades. **; UT, MT and HT indicated unthinned, moderately and heavily thinned grades, respectively in the Table.

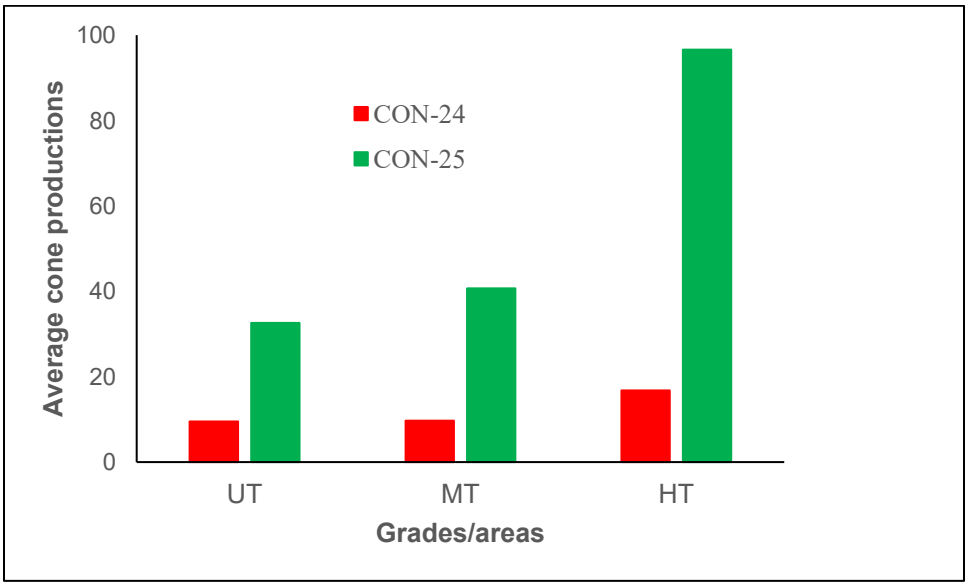
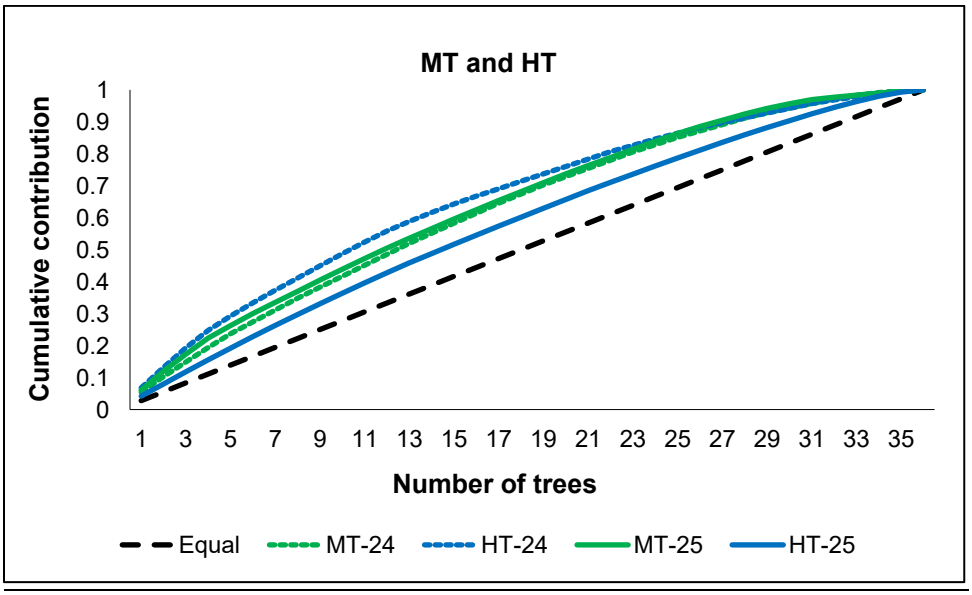


Fig. 4. Average cone production for the grades (UT-Unthinned, MT-Moderately thinned and HT-Heavily thinned) and years-2024 and 2025

Table 3. Results of Analysis of Variance for the Characteristics

Source of Variation	d.f.	H	D_0	DBH	CH	CD	CN-24	CN-25
Between Groups	2	p>0.05	p<0.01	p<0.01	p>0.05	p<0.05	p<0.01	p<0.01
Within Groups	111							
Total	113							



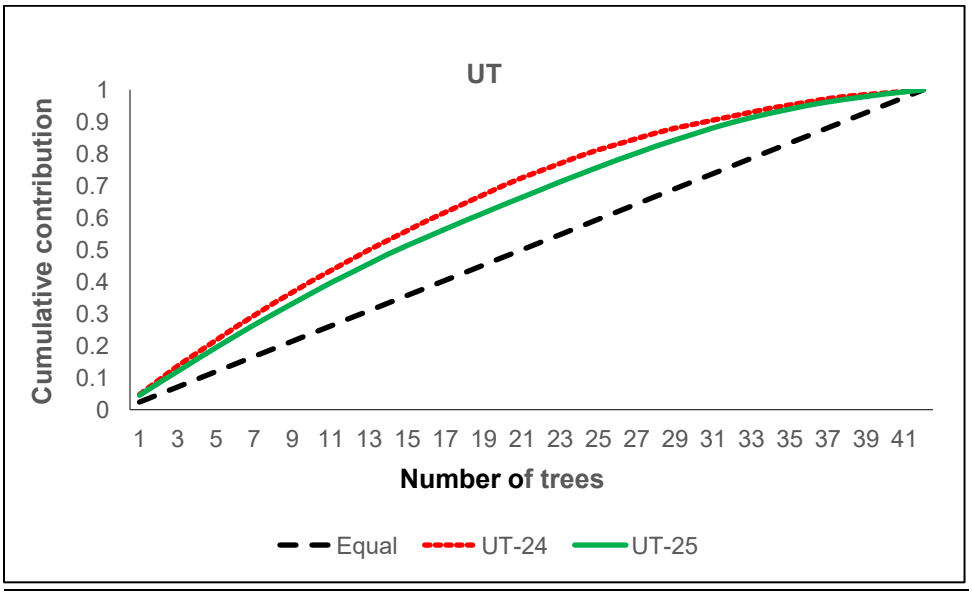


Fig. 5. Cumulative contribution of Parental-balance curves in grades and years

Correlations among the Characteristics

Results of correlation analysis emphasized that growth characteristics had generally significant ($p<0.05$) effect on cone production in both grades and years (Table 4). As can be seen from Table 4, there were also positive and significant ($p<0.05$) relations for cone productions between years in all grades.

Table 4. Relations Among the Characteristics for the Areas and Years

	r[a]	H	D_0	DBH	CH	CD	CN-24
UT		1					
MT	**H**	1					
HT		1					
UT		.599**	1				
MT	**D_0**	.730**	1				
HT		.447**	1				
UT		.514**	.911**	1			
MT	**DBH**	.727**	.955**	1			
HT		.414*	.882**	1			
UT		.944**	.567**	.511**	1		
MT	**CH**	.730**	.723**	.722**	1		
HT		.964**	.479**	.431**	1		
UT		.528**	.796**	.807**	.600**	1	
MT	**CD**	.984**	.798**	.858**	.633**	1	
HT		.328NS	.648**	.596**	.336*	1	
UT		.782**	.574**	.510**	.755**	.558**	1
MT	**CN-24**	.683**	.721**	.667**	.686**	.451**	1
HT		.375*	.325NS	.501**	.335*	.423*	1
UT		.863**	.579**	.497**	.838**	.545**	.894**
MT	**CN-25**	.679**	.881**	.896**	.679**	.737**	.751**
HT		.248NS	.670**	.689**	.265NS	.516**	.389*

a:**Correlation is significant at the 0.01 level, *correlation is significant at the 0.05 level, NS - correlation is not significant at the 0.05 level.

Diameter at breast height (DBH) was a better reflector of cone productions in each grade (r>0.5) and total grades (r>0.5) for both years (Fig. 6). DBH had also significant ($p<0.05$) relations with tree height (H), which support taller trees for receiving more sunlight and water, and to high prone to producing cones (Table 4). DBH was formulated by cone productions of years 2024 and 2025 as: DBH = 14.699 (CON-24), 0.2332 (R^2 = 0.3836, r=0.52), and DBH = 10.159 (CON-25) 0.2374 (R^2 = 0.4408, r=0.54) (Fig. 6). However, the present study was carried out by two-year cone data and limited area. DBH was easily measurable among the growth characters. Similar relations also have been estimated in clonal seed orchards of Scots pine (Bilir *et al*. 2008). The impact of growth characteristics on acorn production was significant ($p < 0.05$) and positive in natural populations of Turkey oak (*Quercus cerris* L.) (Bilir *et al*. 2023) and Mongolian oak (*Quercus mongolica* Fisch.) (Noh *et al*. 2020). However, a different scenario emerged for Scots pine (Nikkanen and Velling 1987), loblolly pine (*Pinus taeda* L.) (Schmidtling 1981), and lodgepole pine (*Pinus contorta* (Dougl.)) (Hannerz *et al*. 2001). The results could be guide for tending practices such as pruning in forestry to increase cone production.

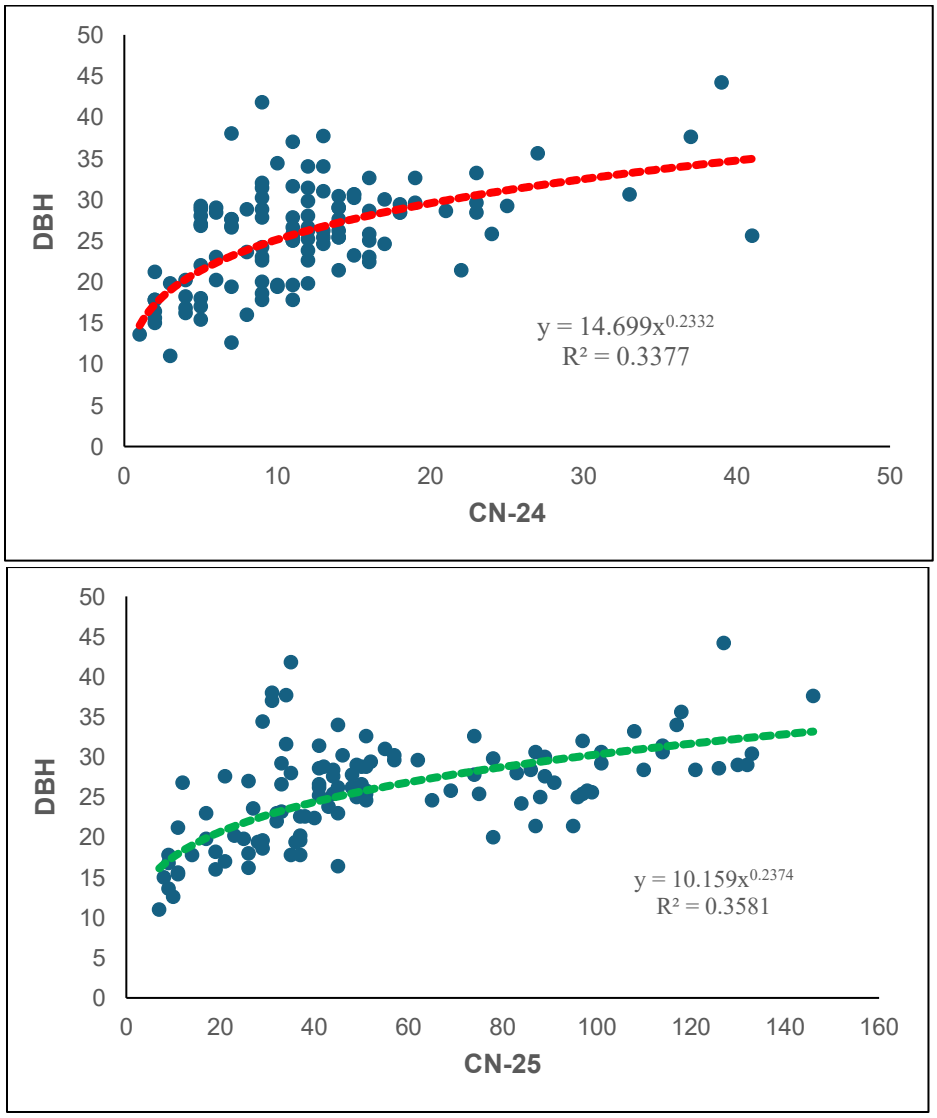


Fig. 6. Correlation between DBH and cone productions (CN-24 and CN-25) for total grades

CONCLUSIONS

1. Stands that were subject to different levels of thinning, as well as individuals within stands showed variations for both cone production and growth characteristics. Trees within heavily thinned stands had the highest cone production for both years. Significant ($p < 0.05$) differences were found among/grades for most growth characteristics and cone productions.
2. Thinning practices carried out in 2021 had a positive and significant impact on cone production in a short period. These results suggest that thinning could be an environmentally friendly management practice for higher cone production in seed collection and natural regeneration areas.
3. Growth characteristics had generally significant ($p < 0.05$) impact on cone production. Diameter at breast height was better reflector of cone productions. The study was carried out by limited thinning grade and year. New studies could be carried out in different locations and years to give detailed conclusions.

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