



Abnormal shoots of *Pinus koraiensis* seedlings under experimental warming and drought

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This study was aimed to investigate the effects of experimental warming and drought on abnormal shoots of *Pinus koraiensis* seedlings, which is a fixed-growth species, in Korea. Ninety 2-year-old *P. koraiensis* seedlings per plot (1 m x 1.5 m) were planted in May, 2016, and were treated by the combination of 2 temperature levels (control (TC) and warming (+3 °C; TW)) and 2 precipitation levels (control (PC) and drought (-30% of precipitation; PD)) with 5 replicates. Phenological stages of abnormal shoots were observed with stages 1: slight swelling, stage 2: swollen bud and shoot elongation, stage 3: budburst, and stage 4: needle growth in September, 2017 and October, 2018 when the phenological development of abnormal shoots were completed. There were no significant changes in the occurrence rate of abnormal shoots by the drought treatment. Previous studies reported that abnormal shoots were generally produced under enough water condition. Since summer precipitation in Korea was high (total precipitation of study site in August: 102.7 mm in 2017 and 229.8 mm in 2018), the absence of drought effect might be explained by enough precipitation even in PD plots. The occurrence rate of abnormal shoots was higher in TW plots ($91.3 \pm 2.6\%$) than in TC plots ($66.8 \pm 5.3\%$) in 2017 ($p=0.0007$), whereas it was lower in TW plots ($77.3 \pm 4.7\%$) than in TC plots ($90.2 \pm 2.5\%$) in 2018 ($p=0.0272$). Some of abnormal shoots in TW plots developed to stage 4 in 2017, while the highest stage of abnormal shoots in 2018 was stage 2 in all plots. The mean air temperature in August was 25.9 ± 0.1 °C in TC plots and 28.7 ± 0.1 °C in TW plots in 2017, and 29.1 ± 0.1 °C in TC plots and 31.5 ± 0.2 °C in TW plots in 2018, respectively. Taken results of both years together, the occurrence rate of abnormal shoots were parabolically related to the mean air temperature in August ($r^2=0.4129$, $p < 0.0001$). It was reported that increasing summer temperature stimulated the formation of leaf primordia in bud which resulted in the elongation of abnormal shoots. Abnormal shoots seemed to be produced and developed by warming in 2017. However, temperature exceeding the threshold might act as stress to primordia, and decrease the occurrence rate of abnormal shoots by warming in 2018.

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