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The more, the better? Water relations of Norway spruce stands after progressive thinning

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ABSTRACT

Predicted intense and prolonged drought events challenge forest management. Thinning is debated as a silvicultural measure for reducing drought risk in densely established forest stands. We report on a thinning experiment in a 26-year-old Norway spruce stand (*Picea abies*), comprising of two thinning intensities and one unthinnned control. The removal of 43% (moderate thinning, MT) and 67% (heavy thinning, HT) of the initial basal area led to increased water availability during the entire three year observation period. Stand-level transpiration (E_s) was decreased by about 25% upon moderate, and by about 50% upon heavy thinning during the first year after the interventions had been carried out. However, differences in E_s across the treatments decreased within three years after thinning mainly due to increased single-tree transpiration and additional understory evapotranspiration at HT. Nevertheless, due to lower interception and transpiration on the thinned plots three years after treatment MT and HT still showed a substantial surplus in extractable soil water. The results showed that the main determinants concerning the extent of the mitigation effect with increasing thinning intensity were the available soil water storage capacity and the emerging understory vegetation. We conclude that repeated moderate thinning, through enhancing the water availability to the remaining trees, can mitigate drought risk in young spruce stands and thus, represent a viable silvicultural measure in anticipating possible water limitations due to climate change.

1. Introduction

The expected increase in air temperature during growing seasons in combination with severe and extended periods of drought (Meehl and Tebaldi, 2004) challenge forest management all over the world: decreasing primary productivity or whole-stand decline caused by pest may threaten forestry (Ciais et al., 2005; Bréda et al., 2006; Rouault et al., 2006). Present forest management strategies for counteracting the consequences of climate change in Central Europe are to diversify tree species composition and to convert mono-specific stands of drought sensitive species into mixed-species stands (Bolte et al., 2009).

Norway spruce (*Picea abies* [L.] *Karst.*), a drought sensitive tree species, may be severely affected by climate change (Ammer et al., 2008; Kölling et al., 2009; Temperli et al., 2012). However, in Germany, Norway spruce occupies more than 3.3 million ha (c. 30% of total forest area) 32.7% of the Norway spruce stands are still even-aged and mono-specific (BMELV, 2008). In Bavaria (Southern Germany), even 43% of the forests consist of pure Norway spruce, which is by far the economically most important tree species in Germany. However, on sites where its future cultivation in monocultures is questioned, spruce stands older than 60 years may be replaced by another more drought tolerant species or they may be converted into mixed stands by under-plantings with a different tree species (for review see Ammer et al., 2008). This is no option for the Norway spruce stands <40 years of age growing on more than 1.0 million hectares in Germany (BMELV, 2008).

Therefore, the question arises whether silvicultural interventions may help to mitigate the risk of drought on young Norway spruce stands. One frequently discussed option is thinning (Bolte et al., 2009). Experimental evidence from different studies covering a variety of species suggests that thinnings may help to substantially reduce climatic stress by augmenting water supply (Lagergren

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et al., 2008; Magruder et al., 2013; Hawthorne et al., 2013; Giuggiola et al., 2013). Moreover retrospective tree ring analyses revealed trees of thinned stands to be favoured in recovery after exceptionally dry years (Kohler et al., 2010; Sohn et al., 2013). D'Amato et al. (2013) confirmed these findings but only for young stands. Reversal effects were found for old stands. However, dendro-chronological studies cannot fully disentangle thinning effects from such of climate on growth (Laurent et al., 2003).

Common silvicultural thinning practice in immature Norway spruce stands is promoting the future crop trees in growth and stability by reducing light competition through successively removing competitors (Röhrig et al., 2006). Although effects of thinning intensity and frequency have been repeatedly studied on single tree performance and stand growth, structural development and wood properties (Misson et al., 2003; Mäkinen and Isomäki, 2004; Jaakkola et al., 2005a,b; Slodicak et al., 2005; Cao et al., 2008; Wallentin and Nilsson, 2011), much less is known on the effect on tree water consumption and stand water balance. As for light (Binkley et al., 2013) the response of single trees to improved soil water conditions may be completely different from the response of the entire stand. Thus, thinning may increase single-tree transpiration due to increase in light, air flow in the crown and water availability but reduce stand water consumption on a short-term scale (Morikawa et al., 1986; Aussenac and Granier, 1988; Hager, 1988; McJannet and Vertessy, 2001; Simonin et al., 2006, 2007). Water interception is decreased while the water status of the remaining trees is improved due to rising soil moisture (Donner and Running, 1986) Conversely, in some studies the thinned stands showed increasing transpiration, already after the second year (Stogsdill et al., 1992; Bréda et al., 1995; Lagergren et al., 2008).

The differing results may partly be explained by thinning intensity. As Aussenac and Granier (1988) reduced total basal area of a Douglas fir stand (*Pseudotsuga menziesii* var. *menziesii*) down to 50%, which resulted in increased soil water reserves during at least the three subsequent years, Bréda et al. (1995) and Lagergren et al. (2008) performed less intense thinnings (basal area removed 35% and 25% respectively). Although Stogsdill et al. (1992) reduced basal area down to 50% and 75%, improved water availability occurred only during humid years, due to increased throughfall. However, the water status of an entire stand is controlled by both the residual trees after thinning and the understory vegetation which may establish shortly after the silvicultural intervention.

To our knowledge understory effects on ecosystem-level water consumption after thinning have been considered only by Simonin et al. (2007). They showed that in dry years the contribution of understory evapotranspiration compensated the lower overstory evapotranspiration. In summary, it can be concluded that the reliability of thinning for mitigating drought risk is not yet clear. Overall, knowledge and mechanistic understanding of graduated thinning affecting stand-level water relations and productivity, taking water consumption by trees and understory vegetation into account, is scarce.

In this study, we report on an experiment in a mono-specific Norway spruce stand where two thinning intensities were carried out and compared with an unthinned control. The aim of our study was to clarify to which extent increasing thinning intensity may promote water availability of the remaining trees in parallel to reducing the stand-level water consumption. Both the water demand of tree and understory vegetation were taken into account. It was hypothesized (i) that increasing thinning intensity decreases stand-level transpiration while increasing soil water content, (ii) that such effects decline over time due to increases in tree and understory transpiration and understory interception, and (iii) that the water use efficiency of target trees released from competition is lower than that of control trees.

Table 1
Stand characteristics: mean basal area per tree (BA tree^{-1}), leaf area index of the stand (LAI), stand basal area (BA ha^{-1}) and stand sapwood area (A_s ha^{-1}) of the unthinned control plots (NT), moderately thinned plots (MT) and heavily thinned plots (HT) before and upon thinning in 2009^{-1}.

	NT	MT	HT
Before thinning (January 2009)			
BA tree^{-1} (m^2)	0.014	0.013	0.014
LAI	10.8	10.6	11.5
BA$_s$ ha^{-1} (m^2)	42.4	42.4	47.0
A_s ha^{-1} (m^2)	30.3	30.3	33.8
After thinning (March 2009)			
BA tree^{-1} (m^2)	0.014	0.013	0.020
LAI	10.8	6.5	3.4
BA$_s$ ha^{-1} (m^2)	42.4	24.1	14.1
A_s ha^{-1} (m^2)	30.3	17.2	10.1

2. Materials and methods

2.1. Experimental stand and site

The study was conducted near Landshut (48°38′20″ N, 11°57′49″ E, Bavaria, Germany) in a monoculture of Norway Spruce (*Picea abies* [L.] Karst.). The mean annual precipitation in the region reaches 778 mm and the mean annual temperature was 7.9 °C (DWD). The stand was planted in 1982 on luvisol (loess over tertiary) with approx. 3700 seedlings ha^{-1}. Available soil water storage capacity (ASWSC) reached about 160 l m^{-2} (per ground area down to 60 cm soil depth).

The experiment was initiated in 2008 and has continuously been monitored since that time. The research area (75 m × 50 m) was subdivided into 6 plots of 25 m × 25 m each. In January 2008 the stem diameter at breast height (1.30 m, DBH) of all trees was measured and their co-ordinates were mapped. Prior to initiation, about 430 future crop trees (target tree) per hectare were selected. Target trees were defined as dominating vital trees (in most cases the trees with the highest diameter). DBH increments of all trees were recorded after each growing season and up-scaled to stand level.

In February 2009 four out of six randomly selected plots were thinned, while two plots remained unchanged as control (NT = not thinned). Two plots each were moderately (MT) or heavily thinned (HT; Table 1; Fig. 1). MT represented the stand treatment commonly carried out in Germany, i.e. thinning from above by removing two competitors per target tree on average. MT reduced stand basal area by c. 43.0%. On HT all trees but the target trees were removed, resulting in BA reduction of c. 67.0%. Thinning was performed by a harvester. Motor-manual felling were done inside the centre of

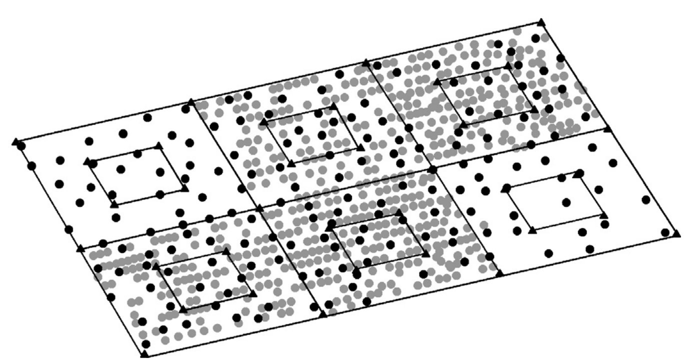

Fig. 1. The research area (75 m × 50 m), subdivided in 6 plots of 25 m × 25 m with an inner intensive measurement area 10 m × 10 m each (triangle). Each circle represents one tree. About 430 future crop trees (target trees) per ha (black circles) were selected prior to thinning. Four out of the six randomly selected plots were thinned, while two plots remained unchanged as control (NT = not thinned). Two plots each were moderately (MT) or heavily thinned (HT).