Shading effects of trees revealed using TLS and QSMs

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1. Introduction

Terrestrial laser scanning (TLS) is a consistent technique for the 3D digitization of landscapes, which is enabling the quantification of landscape components with unprecedented level of details and accuracy. This effective, precise and non-invasive technology is ideal for assessing tree form and stand structure, as well as monitoring temporal dynamics of forests and agroforestry systems.

An established methodology is to scan trees from multiple positions, followed by the extraction of individual tree point clouds, and the reconstruction of tree structures with cylinder-fitting algorithms (e.g. *TreeQSM*, Raumonen et al. 2013). The retrieved tree structures are often called quantitative structure models (QSMs). These contain essential topological, geometrical and volumetric information related to functional properties of the scanned tree. The QSMs present the opportunity to measure and manipulate tree structures in order to study manifold ecological issues, e.g. the light availability at ground level under. Initial work by Rosskopf et al. (2017), and Bohn Reckziegel et al. (2021), has demonstrated the potential of combining QSMs with the inclusion of virtual leaves to assess the shading effects of trees. Furthermore, the selection of targeted branches is possible by retrieving QSM-cylinders matching specific database queries.

In this study, we aim to quantify the changes in insolation reduction caused by tree structures reshaped by pruning treatments. We use field-tested pruning approaches as guidance for our computer-based pruning simulations to the QSMs. The application of analogous tree structures for creating multiple pruning and shading scenarios is innovative. Finally, virtual pruning of tree structures can support the design and selection of adequate tending operations to control light distribution in agroforestry systems.

2. Data and Methods

We selected four wild cherry trees (*Prunus avium* L.) belonging to a widely spaced tree plantation located in the proximity of Breisach, southwest Germany (48°4’24’’N; 7°35’26’’E, 182 m a.s.l.). Trees were digitized from a minimum of four scan positions with a terrestrial laser scanner Z+F IMAGER ® 5010 (Zoller+Fröhlich GmbH, Wangen, Germany), under leaf-off conditions. The 3D structures of the four trees were retrieved with the MATLAB implementation of *TreeQSM* version 2.3 using the segmented tree point clouds.

We defined pruning treatments according to Springmann et al. (2011) including low and high intensity variants: removal of complete whorls as a conventional approach (p5w and p3w), and; removal of branches according to branch collar diameter and/or angle in relation to the stem, as a selective approach (p3d and p2d). The pruning treatments were implemented as algorithms written as independent functions in the open source language R version 3.5.3 (R Core Team 2019), to retrieve QSM-cylinders matching the specific database queries.

The resulting 20 tree structures were fed into a shadow model (Bohn Reckziegel et al. 2021) with fine spatiotemporal resolution to simulate the shade cast over a twelve months period (October 2013 until September 2014), and to estimate the insolation reduction on the ground. Shade projections were simulated for a quarter of a hectare with a grid-cell size of 10 cm x 10 cm, and time steps of 10 min, while factual solar radiance data from a nearby weather station were added to the model.

Published in: Markus Hollaus, Norbert Pfeifer (Eds.): Proceedings of the SilviLaser Conference 2021, Vienna, Austria, 28–30 September 2021.
Technische Universität Wien, 2021. DOI: 10.34726/wim.1861
This paper was peer-reviewed. DOI of this paper: 10.34726/wim.1910

3. Results

The four trees differed in terms of total wood volume and crown characteristics, hence the simulated pruning interventions removed from 32% up to 59% of the tree's total volume. Low intensity pruning regimes varied for each tree both in relative and absolute terms, with an absolute difference ranging from 1.2 litres to a maximum difference of 5.5 litres. In between the high intensity approaches, selective pruning was less invasive than the conventional pruning. Total leaf area of the retrieved tree structures stayed below 50% of unpruned trees.

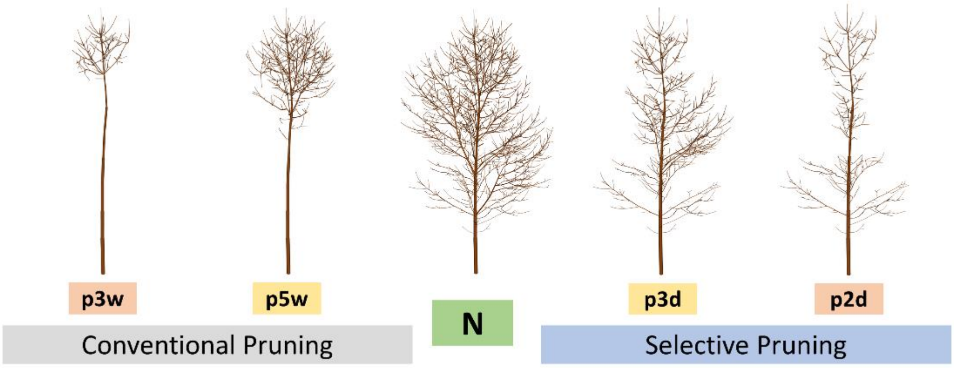

Figure 1 – Example of unpruned (N) and pruned variants of the same tree: left, conventional pruning; right, selective pruning; in yellow, low intensity pruning variants (p5w, p3d); in orange, high intensity pruning variants (p3w, p2d).

The control trees had the greatest shading effects; these were greater in area and in insolation reduction than any of the pruned variants (Table 1). Although shaded area varied throughout trees and treatments, selectively pruned trees had greater insolation reduction than conventional pruning.

Table 1 - Shading effects of unpruned and pruned structures of tree T1 for the simulation period of October 2013 to September 2014.

Tree	**Shaded Area**	**Total Insolation Reduction**	**Mean Insolation Reduction**	**Mean Daily Insolation**	**Mean Daily Insolation Reduction**
	m^2	**MJ**	**MJ m^{-2}**	**MJ m^{-2} day^{-1}**	**MJ m^{-2} day^{-1}**
T1N	333.5	54,346	162.9	11.67	0.45
T1p3d	262.4	37,864	144.3	11.72	0.40
T1p2d	227.6	30,125	132.4	11.75	0.36
T1p5w	220.7	23,499	106.5	11.82	0.29
T1p3w	136.8	13,148	96.1	11.85	0.26

* Yearly insolation under "full light conditions" of 4,422 MJ m^{-2} yearly and 12.11 MJ m^{-2} day^{-1} for the simulated period.

The spatial distribution of the annual shading effects of the unpruned and pruned T1 are shown in Figure 2. We found similar arrangement and trends for the shading effects of the trees. Overall, we noticed a smooth reduction in insolation spreading more than 20 m largely to the north of the sample tree. In a zoomed viewpoint, the grid-cells with more intensive insolation reduction can be seen. The control treatment showed a highly shaded centre, with a centralized higher insolation reduction four to eight meters from the tree position towards the north. Selectively pruned trees displayed similar patterns than the control treatment, although with reduced shaded area and less intense shading at the core. Conventional pruning softened the shading effects of all trees, with exception of a condensed semicircle arc spreading approximately four meters away from tree trunk, which is a clear manifestation of the resultant crown shape.

4. Discussion

High intensity pruning simulations suggested a removal of up to 60% of total tree volume, which could make these treatments too severe to be applied in reality. The low intensity treatments had a more appropriate removal of woody biomass (≈40% of tree volume). A change in the parameterisation of the pruning functions could be required for applying these same treatments to other tree species. The assessment of the annual insolation reduction showed that selective pruning is an option to attenuate the shading effect of tree structures, while conventional pruning radically minimizes shading. In areas where shading is relevant for crop production, or for the attenuation of climatic extremes, pre-designed selective pruning interventions are to be prioritized.

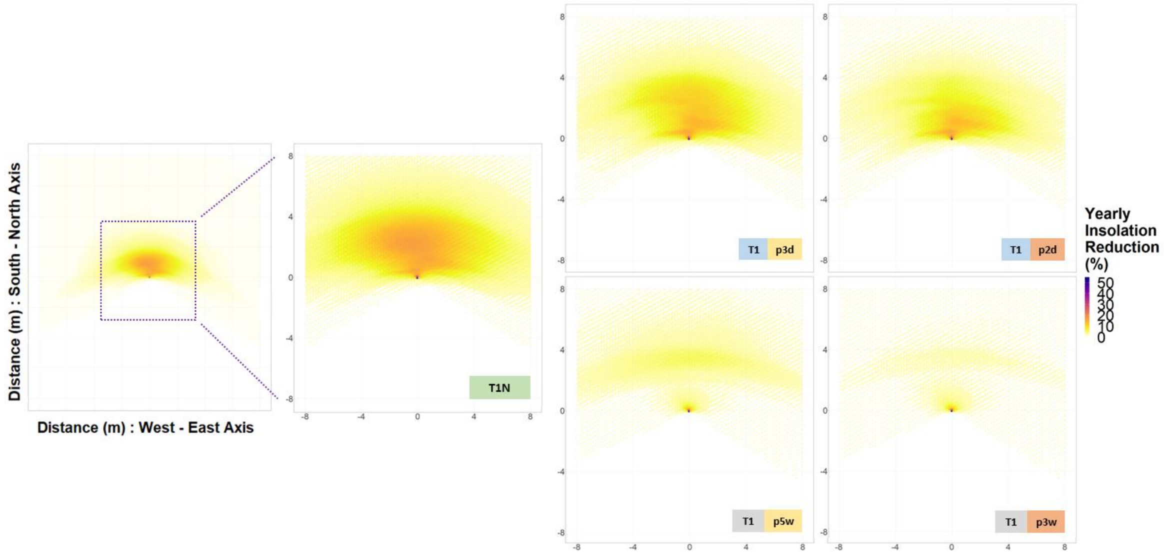

Figure 2 – Shading effects of tree T1 and from its analogous pruned tree structures for the twelve months period.

5. Conclusions

Pruning is a silvicultural intervention capable of influencing the light regime at ground level. Thus, the combined approach presented in this study is a way to facilitate management of the light resource at an individual tree level. It supports decisions about and demystifies the presence of trees in agricultural systems. Besides, virtual pruning of QSMs has the potential to become a tool for investigating, assessing and planning, alternatives to woody biomass production, management of ladder fuels, provision of ecosystem services, and the aesthetic view of landscapes.

Acknowledgements

This research was supported by the German Federal Ministry of Food and Agriculture (BMEL) within the projects Agro-Wertholz (support code 22031112) and SidaTim (support code 2815ERA04C) and by the German Federal Ministry of Education and Research (BMBF) within the ASAP project (grant number 01LL1803A).

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