SIMULATION OF ANNUAL LEAF CARBON FLUXES AND ANALYSIS OF STAND STRUCTURE OF POPLARS AND BLACK LOCUSTS IN AN ALLEY-CROPPING SYSTEM, BRANDENBURG, GERMANY

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Abstract

Carbon gain by photosynthesis is significant for plant growth and biomass allocation estimations at a tree, stand, and landscape level. Our objective was to develop a leaf carbon model driven by daily light fluctuations and modulated by temperature and air humidity for poplar and black locust trees in a temperate agroforestry system. Different light regimes and the leaf area index (LAI) were considered for further up-scaling of the CO_2 fluxes. We obtained differences in the light intercepted by both tree species, which lead to drastic implications for the photosynthesis, leaf development, and stand structure. The LAI followed the declining pattern of the tree heights from leeward to windward strips and with respect to the sun-exposed crown. Our results highlight the importance of light competition and stand structure for the growth performance of agroforestry systems and can contribute to optimizing stand densities for either maximum single tree or stand biomass production.

Keywords: agroforestry; alley cropping; leaf carbon flux; leaf area index

Introduction

Planting of trees and shrubs into agricultural systems have ecological and economic benefits as they provide timber, fuel-wood and other products, and have positive effects on the ecosystem functioning (Kanzler et al. 2016; Veste and Böhm 2018). Site-specific species selection and their management are most crucial for a successful biomass production in agroforestry systems. Currently, the selection and planting of tree species are more economically oriented towards optimizing biomass production and poplars (*Populus* spec.) and willows (*Salix* spec.) are mainly cropped due to their high potential of biomass production. Under drier climatic conditions in East-Central Europe, black locust (*Robinia pseudoacacia* L.) is recommended for short-rotation forestry due its high ecophysiological plasticity and biological nitrogen-fixation (Mantovani et al. 2015a, b; Veste and Halke 2017). For a better understanding of growth performance of fast-growing trees in agroforestry systems, more detailed information about carbon fluxes is required. Photosynthesis is a predominant factor for plant growth and is largely influenced by microclimatic factors (light, temperature). Carbon gain by photosynthesis is a predominant factor for plant growth and essential in estimating biomass allocation at a tree, stand and landscape level (Küppers 1988). Our main objective was to develop a leaf carbon model driven by daily fluctuations in light and modulated by temperature and air humidity. The seasonal variation of CO_2 uptake and release can then be modelled to estimate annual carbon fluxes of sun, half-shade and shade leaves of black locust and poplars in a temperate agroforestry system. Furthermore, we investigated the importance of different light regimes on the growth of poplar and the differences of the leaf area index as a basis for further up-scaling of the CO_2 fluxes.

Materials and methods

The study site (51°47´ 24´´ N, 14°37´ 57´´ E) is situated in Lower Lusatia, in the South of the Federal State Brandenburg, Germany, with an average annual precipitation of 581 mm and a mean annual temperature of 9.3 °C (1981-2010, DWD Cottbus). It is part of an agricultural landscape stocking on naturally formed soils (Fluvisols) close to the Lusatian River Neiße.

Figure 1: Alley-cropping systems near Neu Sacro (Brandenburg, Germany).

Hedgerows are comprised of black locust trees (*Robinia pseudoacacia* L., planted in spring 2010) and hybrid poplar trees, clone “Max” (*Populus nigra* L. x *P. maximowiczii* Henry, planted in spring 2011). They were planted in around 170 m long alternating rows (Figure 1) as one-year-old, bare-rooted saplings and cuttings, respectively. Including buffer zones of 1 m between trees and crops, these hedgerows have a width about 10 m at a planting density of about 8,700 trees per hectare woodland. The Hedgerows are oriented in north-south direction (Figure 1). The distance between hedgerows varies between 24, 48 and 96 m.

Photosynthetic parameters of both tree species were obtained via two portable H_2O/CO_2-porometer systems (Li-Cor 6400, Li-Cor Inc., USA, Figure 2). Steady-state light response curves of leaf net photosynthesis were measured at different temperatures on field grown trees. Based on the *in-situ* measurements of leaf gas exchange we used an entirely empirical photosynthesis model (Küppers et al. 2017) to estimate the annual net carbon fluxes of sun and shade on/in leaves of poplar and black locust. The model consists of four sub-models: (i) the effect of leaf temperature on respiration in the dark and (ii) on light-saturated net photosynthesis is calculated separately; (iii) the effect of leaf-to-air vapour concentration is taken into account assuming that this effect is mediated by partial stomatal closure resulting in a relative reduction of the CO_2-uptake and (iv) all these single effects are combined in a light-response of net photosynthesis. The photosynthesis model is driven by microclimatic data, which have been recorded locally throughout the year.

Figure 2: In situ gas exchange measurements.

The leaf area index (LAI) was obtained by a SunScan SS1 LAI meter (Delta-T Devices Ltd, Cambridge, UK) and measurements were replicated at three points per each row (total n=9 per plot). The measurements were conducted during a sunny day, on 2nd of September 2017. Tree heights and breast height diameters were measured at end of October. Light interception in the poplar and black locust trees was measured with quantum-sensors (Li-Cor Quantum sensor) mounted at four different light classes in the canopy and below. PAR was recorded in 2 minutes' intervals by data-loggers and related to a reference sensor exposed on the open field.

Results and discussion

In fully expanded leaves, the light was the major factor determining daily carbon balances. The highest observed daily carbon gain in sun leaves was of 748.9 mmol CO_2 m^{-2} d^{-1} in poplar and of 536.3 mmol CO_2 m^{-2} d^{-1} in black locust. The much higher seasonal carbon gain in sun leaves of poplar hybrid *P. nigra* x *P. maximowiczii* (66,803 mol CO_2 m^{-2}) compared to *R. pseudoacacia* (46,824 mol CO_2 m^{-2}) results from its much longer leaf period, therefore larger total intercepted light. Although the leaf nitrogen content is higher in black locust (2.8% - 4.0%, Veste et al. 2013), poplar leaves showed a much higher photosynthetic capacity (Küppers et al. 2017), which contributed to the higher carbon gain of the species. Differences in light intercepted by the crown varied between the two species and resulted in drastic implications for the photosynthesis, leaf development, and stand structure. Leaves in the lower Robinia crown rendered positive carbon balances when sufficient light reached the ground. From June onwards, the canopy became so dense that predominantly negative daily C-balances were observed and leaf fall commenced. This observation emphasized the importance of light interception in the mono-stands for the productivity of the agroforestry stands. In *Populus*, a higher light fraction penetrated into the understory compared to *Robinia*.

Structural differences between outer and inner rows of the trees can be observed during the second rotation. The height of poplar trees peaked at 7.81 m on the east-facing site, decreasing to 6.00 - 6.41 m in the inner rows and 5.07 m at the west-facing (wind-warts oriented) rows (Figure 3). Robinia reached mean tree heights between 4.97 and 6.48 m (Figure 4) with no differences between outer and inner rows.

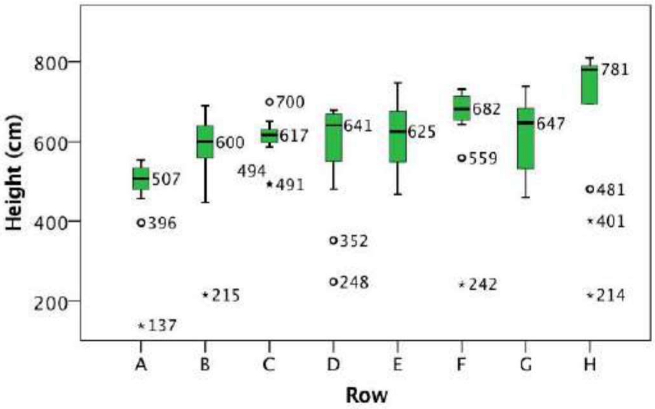

Figure 3: Tree height poplar trees in different rows of an alley-cropping system (A west, H east).

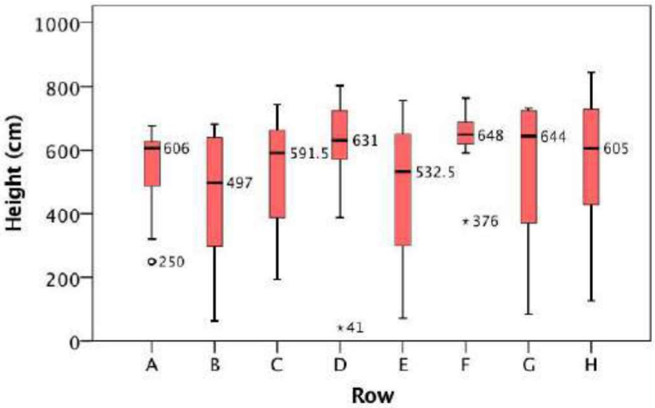

Figure 4: Tree height black locust trees in different rows of an alley-cropping system (A west, H east).

The LAI of poplar trees followed the same declining pattern of the tree heights. The edge effect could also be observed for the LAI of black locust stands, where the outer and sun-exposed crown reached a higher LAI (Figure 5). The access to groundwater enabled the trees for a fast grow and poplar trees at the outer rows (2nd rotation) reached similar heights as the trees in the inner rows (1st rotation, not harvested). Light availability promoted tree growth in the outer rows.

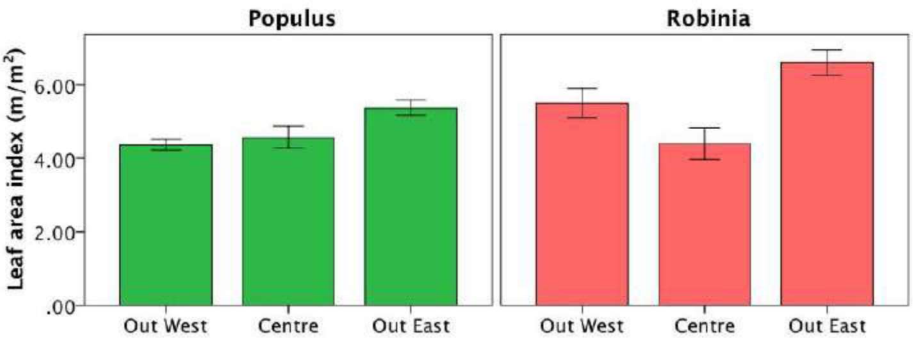

Figure 5: Leaf area index of poplar and black locust in different rows of a alley-cropping system.

Our results emphasized that light competition and stand structure are important factors for the architectural patterns (Küppers 1989) and for the growth performance of agroforestry systems on former agricultural fields. From an agroforestry management viewpoint, this strongly contributes to the question of optimum stand densities for either maximum single tree or stand biomass production, and how far can tree growth reactions be triggered by thinning. The latter contributes to the question to what extent can stand density reactions be compensated by an increased growth of the remaining trees.

This is not only important for short rotation biomass production, but also in midi- and maxi-rotation agroforestry, where single stem wood production can be a production goal. Furthermore, the edge effect along alley-cropping agroforestry systems enhances tree production at the outer rows and we assume that this might contribute to a higher Land Equivalent Ratio of the trees compared to short-rotation coppices (Seserman et al. 2018, this volume).

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