COMPARING LONG-TERM CROP YIELDS OF A SHORT ROTATION ALLEY CROPPING AGROFORESTRY SYSTEM AND OF A STANDARD AGRICULTURAL FIELD IN NORTHERN GERMANY

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Abstract

Alley cropping agroforestry systems (ACS) provide various ecologically positive effects. However, trees and crop plants are competing for essential resources, especially in the transition zone. This study investigated the spatial distribution of oilseed rape and winter wheat yield in the tree-crop competition zone of an ACS with fast-growing poplars and narrow (48 m) and wide (96 m) crop alleys in northern Germany. Furthermore, multi-year crop yield data were compared with those of a corresponding non-agroforestry control field. Crop yields adjacent to the tree strips were significantly lower than at greater distances, mainly due to tree shading and leaf litter coverage. However, the average long-term crop yields of the narrow crop alley, the wide crop alley and the control field did not differ significantly among each other. In conclusion, yield reduction close to the tree strips had no negative influence on the average long-term crop yields of the ACS.

Keywords: agroforestry; alley cropping; crop yield; winter wheat; oilseed rape

Introduction

In short rotation alley cropping agroforestry systems (ACS) crop alleys or grassland and tree strips for energy wood production are arranged in parallel. Tree strips in ACS provide many ecologically positive effects, such as protection from wind erosion (Brandle et al. 2004), reduction of nutrient leaching (Böhm et al. 2013) and contribution to the habitat connectivity (Tsonkova et al. 2012). Litter fall provides an additional source of soil organic matter and can improve the soil properties (Pinho et al. 2012). However, in the transition zone between tree strip and crop/grass alley, trees and cultivated plants are competing for resources such as water, nutrients and light (Jose et al. 2004). In this study, we analyzed the effect of the tree strips on the spatial distribution of oilseed rape and winter wheat yield in a 9-year old ACS in northern Germany. Furthermore, we compared multi-year crop yields of oilseed rape and winter wheat in the ACS with those of a standard agricultural (i.e. non agroforestry) field.

Materials and methods

Our studies were conducted on a short rotation ACS, established in 2008 in northern Germany near the city of Braunschweig at 85 m above sea level. The climate is temperate with an average annual temperature of 9.8°C and an average annual precipitation sum of 616 mm. Local soil properties are rather heterogeneous, the soil in the ACS is mainly characterized by a silty clay texture, whereas the soil in the conventionally cultivated fields is characterized by a clayey loam texture. Yield potential at our study site has been classified as medium to low. The ACS includes 9 tree strips (12 x 225 meters) planted with fast growing poplars for energy wood production, 5 narrow (48 x 225 meters) and 3 wide (96 x 225 meters) crop alleys, each with a crop rotation of winter oilseed rape, winter wheat and winter barley. The same crop rotation was

applied to 3 treeless control fields of about 3 hectares each that are located next to the ACS. Both, ACS-crop alleys and control fields were cultivated site-specific, fertilizer and crop protection products were applied according to regional recommendations and taking soil tests into account. In order to analyze spatial differences in crop yield in dependence on the distance to the tree strips, oilseed rape and winter wheat were harvested at 1, 4, 7 and 24 meters distance from the tree strips using a plot combine. This analysis was conducted in the narrow crop alleys of the ACS in 2016 and 2017. After the harvest, dry matter yields of oilseed rape and winter wheat were determined. From 2009 to 2016, annual crop yield and grain moisture estimation was done with a GPS-equipped harvester on all crop alleys of the ACS as well as on the control fields. The statistical analysis of the yield data was performed with generalized least squares models and linear mixed effects models, using the statistics program RStudio (RStudio Team 2015) and packages nlme (Pinheiro et al. 2017), lme4 (Bates et al. 2015), multcomp (Hothorn et al. 2008), multcompView (Graves et al. 2015), lsmeans (Lenth 2016), effects (Fox 2003), ggplot2 (Wickham 2009) and plyr (Wickham 2011). Firstly, we analyzed the effect of the distance from the tree strip (i.e. 1, 4, 7 and 24 m) in interaction with the orientation of the crop alley towards the tree strip (i.e. windward or leeward) on the oilseed rape (2016) and winter wheat (2017) yield, respectively. Secondly, we analyzed the effect of the cropping system (i.e. narrow ACS, wide ACS, control field) on the long-term crop yield (i.e. yield data from 2009 to 2016). The model selection was carried out using the Akaike information criterion (AIC) (Akaike 1978). Yield data, analyzed in both experiments, only refer to the cropland (crop alleys) area, excluding the area occupied by tree strips.

Results and discussion

Based on AIC, the model with the best fit for the oilseed rape yield took into account the interaction between the distance from the tree strip and the orientation of the crop alley towards the tree strip (windward or leeward). At the leeward side of the tree strip, the oilseed rape yield continuously increased with increasing distance from the tree strip (Figure 1A). The yield at 1 m was significantly lower than the yield at 7 and 24 m from the tree strip. At the windward side of the tree strip, the oilseed rape yield at 1 m from the tree strip was significantly lower than the yield at 4, 7 and 24 m from the tree strip (Figure 1B). Both, at the leeward and at the windward side of the tree strips, oilseed rape yield at 4, 7 and 24 m distance from the tree strips did not differ significantly among each other. The best model for the winter wheat yield took into account the distance from the tree strips. In contrast to the oilseed rape yield, the windward or leeward side of the tree strips had no influence on the winter wheat yield. Similar to the oilseed rape, winter wheat yield increased from 1 m distance to the middle of the crop alley (Figure 2). Yield at 1 m distance from the tree strips was significantly lower than the yield at 4, 7 and 24 m, respectively. The latter did not differ significantly among each other (Figure 2).

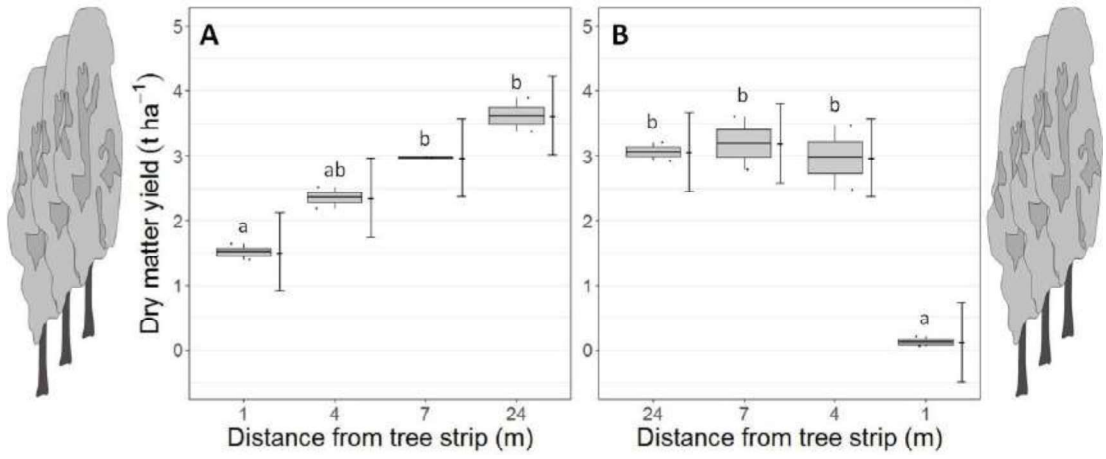

Figure 1: Boxplots with overlaid scatterplots showing oilseed rape yields at different distances from the tree strips at the leeward (A) and at the windward (B) sides of the crop alley, respectively. Error bars are the confidence intervals of the selected model. Different small letters indicate significantly different yields ($p \leq 0.05$).

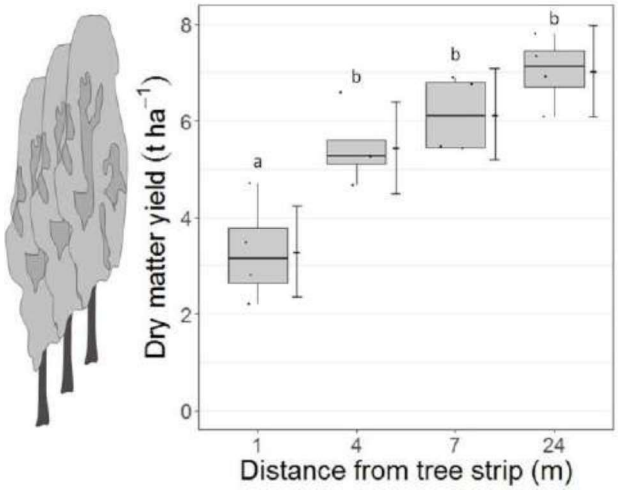

Figure 2: Boxplots with overlaid scatterplots showing winter wheat yields at different distances from the tree strips. Error bars are the confidence intervals of the selected model. Different small letters indicate significantly different yields ($p \leq 0.05$).

In general, yields at 1 meter from the tree strips were significantly lower than at 4, 7 and 24 meters from the tree strips. This might result from negative effects of the trees on the crop plants, such as competition for light, water and nutrients or leaf litter coverage of the seedlings in autumn. The extremely low oilseed rape yield at 1 meter windward from the tree strip, results from a very low plant density. It is supposed that sowing of oilseed rape seeds at 1 m from the tree strips in previous autumn was hampered by the trees.

The average long-term crop yields for oilseed rape and winter wheat for the narrow ACS, the wide ACS and the control field did not differ significantly among each other, i.e. there was no significant difference between the three cropping systems (Figure 3). By trend, crop yields of the narrow ACS were slightly lower than those of the wide ACS as well as the control field. This might be explained by a higher percentage of competition zone area (i.e. crop area close to the tree strip with reduced yields) in the narrow ACS compared with the wide ACS (Figure 1 and Figure 2). Especially in years with low precipitation, when competition for water between trees and crop plants was strongest, crop yield in the narrow ACS tended to be lower than in the wide ACS and the control, respectively. Statistical analysis of long-term crop yield data of oilseed rape and winter wheat revealed a great amount of unexplained variability, suggesting the influence of further factors on crop yield, such as distance from field edge, soil properties, tree height, weather conditions and microclimate. However, when comparing the productivity of the ACS and the control field, not only the area-specific crop yields should be taken into account but also the productivity of the tree strips. On the one hand, the area of the tree strips in the ACS reduces available land for crop production, but on the other hand, the tree strips produce up to 16 t ha^{-1} biomass (Lamerre et al. 2015) for bioenergy generation per year. Thus, in the long term, there is an economic gain from the tree strips.

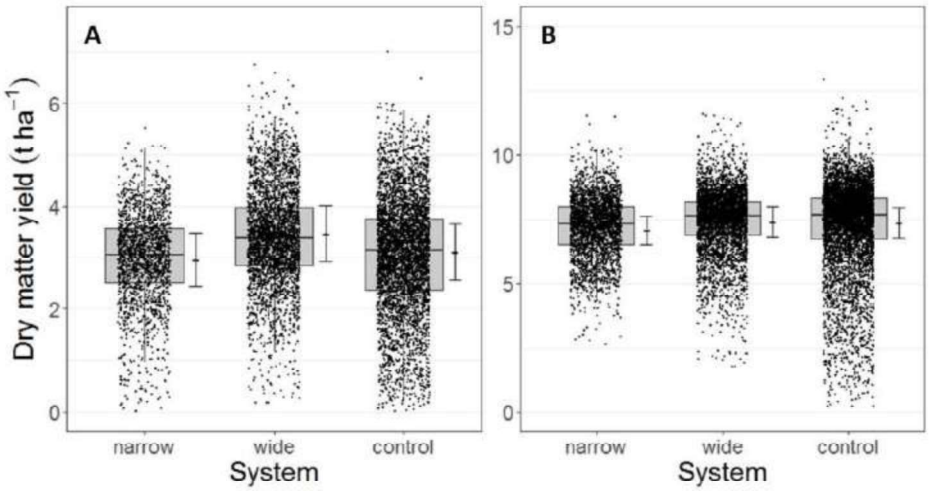

Figure 3: Boxplots with overlaid scatterplots showing winter oilseed rape (A) and winter wheat (B) yields of the years 2009-2016 for the crop alleys in the narrow alley cropping agroforestry system (ACS), the wide ACS and the control field. Error bars are the confidence intervals of the selected model.

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