Sugar beet yields in an alley cropping system during a dry summer

J. Mirck*[1], M. Kanzler[1], C. Boehm[1], D. Freese[1]
[1]Department of Soil Protection and Recultivation, Brandenburg University of Technology Cottbus-Senftenberg, Germany
*Corresponding author

Abstract: Agroforestry (the integration of trees with crop and/or livestock production) offers a pathway to diversify agricultural production. Agroforestry systems have the potential to improve on-farm use of water through enhanced soil water holding capacities, the provision of shade, and the creation of wind shelter. These three characteristics can also improve the resilience of agricultural production in response to changing weather patterns. The objectives of this study were: 1) to measure how alley cropping systems with varying alley widths affect crop microclimate, 2) to measure the effects of this microclimate on sugar beet (Beta vulgaris) yields, and 3) to assess how moisture availability affects sugar beet growth patterns. Measurements were made in a 70 ha alley cropping system comprising black locust (Robinia pseudoacacia L.) and hybrid poplar Max1 (Populus suaveolens subsp. maximowiczii x P. nigra). A sugar beet crop was grown during the relatively dry growing season of 2015. Sugar beet yields were reduced in close proximity to the hedgerow, but yields were higher at and beyond an intermediate distance when compared with those in a nearby conventional agricultural field. Moisture availability significantly affected growth patterns of sugar beet roots.

Keywords: agriculture, agroforestry, *Beta vulgaris*, microclimate, *Populus* spp, *Robinia pseudoacacia*

1 Introduction

Silvoarable agroforestry is the mixed cultivation of arable crops and trees on a single parcel of land. It has the potential to combine food, feed, fibre and renewable energy production (USDA, 2011). It is also a land management approach that can maintain or increase productivity and profitability whilst enhancing ecosystem services. Agroforestry can also help control wind and water erosion, minimise water losses from evaporation, reduce nutrient losses, and help stabilize soil organic matter (Quinkenstein et al. 2009).

The State of Brandenburg is known for its light sandy soils that are prone to wind erosion. The introduction of tree hedgerows within the agricultural landscape can reduce wind erosion (Boehm et al., 2014). In addition, microclimatic conditions such as soil moisture, wind speed, relative humidity and air temperature can be more favourable for plant growth in crop alleys compared to reference crop areas (Boehm et al., 2014; Quinkenstein et al., 2009). Evapotranspiration rates can be reduced in close proximity to the trees due to the shelter effect (Monteith et al., 1991; Gruenewald et al., 2009), but the tree and crop components can also compete for light, water and nutrients. The intensity of interactions between the two components is likely to be weather dependent, with water competition being greatest during dry and hot summers.

Agroforestry for arable farmers is not a common practice in Germany. However, alley cropping for woody biomass production is of interest because of the potential to concurrently provide a biomass feedstock and an arable crop. One of the systems, that exists at an experimental level, is the integration of rows of fast growing trees, such as poplar or willow, with arable crops. Water use for cereal crops such as wheat has been studied in a silvorable system (Burgess et al., 1996), but sugar beet has rarely been researched within the alleys of these systems.

Sugar beet is a common crop within arable systems in Western Europe. As part of agroforestry systems, sugar beets have rarely been studied. Even though sugar beets can root up to a depth of 2 m, their yields can be significantly reduced due to a lack of water (Hoffmann, 2010; Bloch et al., 2006). Agroforestry systems that consist of tree hedgerows and crop alleys, also known as "alley cropping" systems, can increase soil moisture in comparison to conventional agricultural systems (Quinkenstein et al., 2009), and hence such systems, relative to a conventional arable system, could improve sugar beet yields during dry years. This study aimed to assess tree hedgerow effects on sugar beet. The objectives of this study were: 1) to measure how alley cropping systems with varying alley widths affected crop microclimate, 2) to assess how tree hedgerows planted at three distances affected sugar beet yields; and 3) to assess the effects of drought stress on sugar beet yield.

2 Material and methods

2.1 Site description

The study site is located on a 70 ha area of agricultural land owned by the Agricultural Cooperative Forst in Neu Sacro in close proximity to the city of Forst (Lausitz) in Germany. The land has been actively used for conventional agriculture during the last decennia. An alley cropping system of which the tree hedgerows consist of short rotation coppice fast growing woody crops poplar (*Populus nigra L.*× *P. maximowiczii* (variety Max 1)) and black locust (*Robinia pseudoacacia*) was established on the site in 2010. The poplars did not establish well during the first year and were replanted in 2011. The sugar beet yield study took place in the western part of the alley cropping system and on a nearby conventional agricultural field (Figure 1).

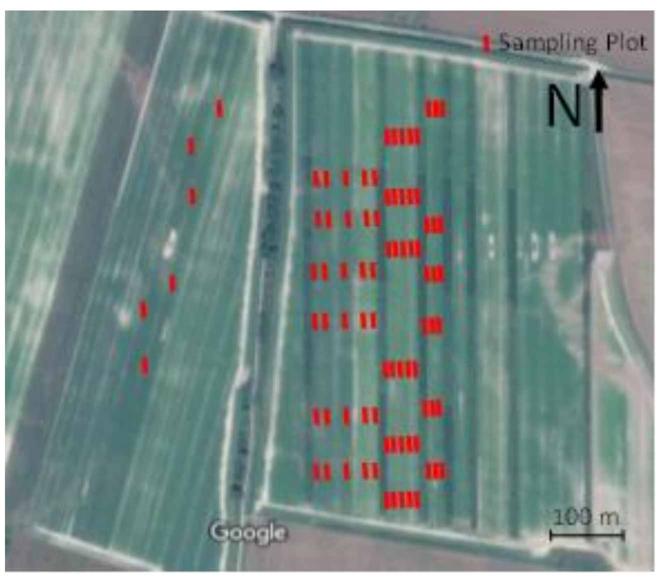

Figure 1. Map of the alley cropping research trial at the Agricultural Cooperative Forst in Neu Sacro (Lausitz), in Germany. Coloured squares indicate sampling plots for the manual sugar beet harvest (map source: Google Maps).

The spacing within the hedgerows was four double rows with 75 cm within the double row, 1.8 m between the double rows and 90 cm within the row. The tree hedgerows are 12 m wide, which includes a buffer strip of 1.8 m on both sides. The tree hedgerows were harvested in February

2015. The crop alleys are 96, 48, and 24 m wide. The main soil type is Gley-Vega, with groundwater levels varying between 1 and 2.5 m below the surface. The top soil is a loamy sand and the subsoil pure sand with gravel layers, with clayey areas (Boehm et al., 2015).

2.2 Sugar beet yield study

The sugar beet crop was sown within the crop alleys and on an adjacent conventional agricultural field during the middle of April 2015. A manual harvest of sugar beets at the study site took place between 30 September and 6 October 2015. Measurements took place at the three western crop alleys of the alley cropping system (Figure 1). Within the alley cropping system both crops in close proximity to the tree rows and crops in the middle of the alleys were harvested in order to assess tree-crop interactions (Rao and Coe, 1991). For the 96 m and 48 m wide crop alleys crop plots were measured at 3 m, 12 m east and west of the tree row and in the centre of the alley and for the 24 m wide alley at 3 m east and west of the tree row and in the centre. Six replications were carried out for each treatment. Sampling plots were approximately 3-5 m² in size and consisted of three sugar beet rows. Prior to sugar beet extraction all beets within the sampling plot were counted and the exact plot size was measured. These values were required for subsequent yield calculations. For sugar beet harvest in each of the plots the following protocol was used: 1) above- and below ground biomass of 12 sugar beets were harvested and weighed separately; 2) two sugar beets were collected for dry matter determination. From the two beets for dry matter determination subsamples were stored in ziploc bags, transported to the laboratory, fresh weight was measured and they were dried until a constant weight at 105°C.

2.3 Sugar beet drought stress

The effect of drought stress on sugar beet yields was measured through harvesting 10 sugar beets from an area of the field with low water holding capacity and 10 sugar beets from an area with higher water holding capacity. These sugar beets were collected on 19 October 2015. Five sugar beets from each location were sent away to assess sugar (sucrose) content polarimetrically at Institute für Produktqualität (IFP). Pictures were taken from a circular cut of the remaining sugar beets and these pictures were analysed with the software Image J. This software was used to measure diameter and to count the number of cambium rings and their thickness. After the pictures were taken fresh weight of the circular and a perpendicular cut were measured and afterwards they were dried at 105°C until a constant weight and dry weight calculations.

2.4 Statistical analysis

Statistical analysis was carried out using SigmaPlot 12.5 (Systat Software GmbH, Erkrath, Germany). Differences in sugar beet yields between the alley cropping system and the conventional crop reference site were assessed separately for each of the alley widths with two-way ANOVAs (Dunnett's method). Differences between the drought stressed and non-drought stressed sugar beets were analyzed using t-tests. For all statistical test we used a significance level of $\alpha = 0.05$ unless mentioned otherwise.

3 Results

3.1 Effect of location and alley width on yield

Long dry spells occurred in May, August, and between the end of September and the beginning of October. For the period between May and October 2015, the rainfall received in the reference site was similar to that in the three alley widths, although rainfall total tended to be smaller in the 48 m and the 24 m alleys (Figure 2). A comparison between the monthly precipitation sums between 1985 and 2014 and the measurements in the alley cropping system during the 2015 growing season indicated that May and August were much drier than normal.

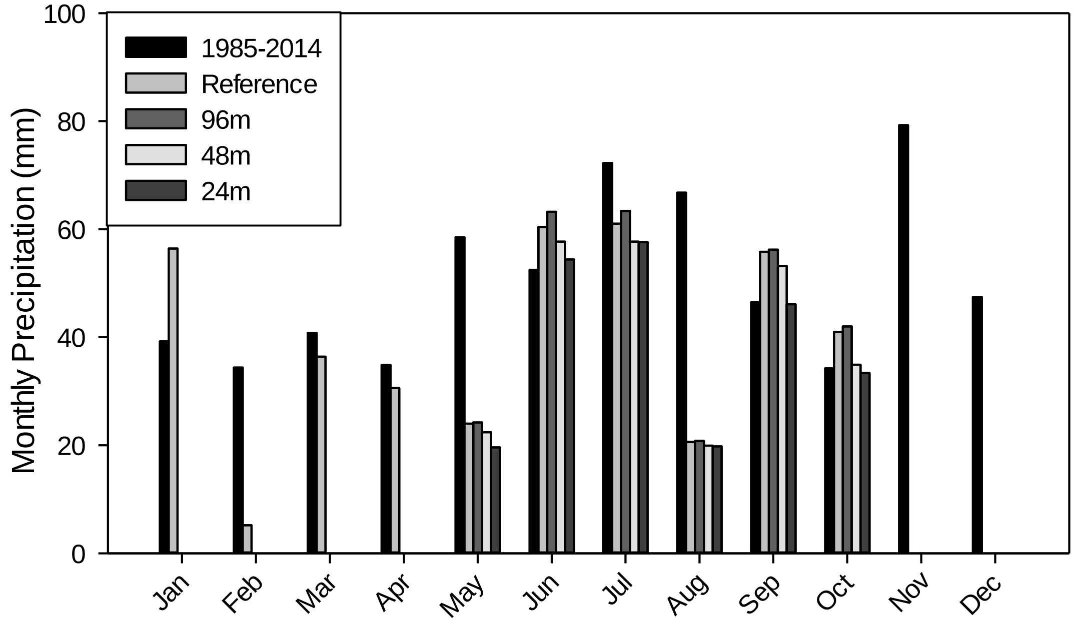

Figure 2. Monthly precipitation (May to October) for the reference and experimental locations within the Alley Cropping System Research Trial site for 2015 with the historical monthly precipitation sums (1985-2014) from a nearby weather station from the German Weather Service in Cottbus, Germany (ftp://ftp-cdc.dwd.de/pub/CDC/observations_germany/climate/monthly/kl/historical/).

Sugar beet yields tended to show a reduction in close proximity to the tree hedgerow and an increase at 12 m and in the middle of the alleys in comparison with the adjacent reference crop field (Figure 3A). Significant differences were present between the mean yields in the five sampling points and that at the reference site for the 96 m ($p = 0.026$) and 48 m ($p = 0.004$) alleys. No significant differences among the sampling locations and the reference site were measured for the 24 m alley ($p = 0.297$). Multiple comparisons compared each sample location within the crop alley with the reference field (Dunnett's); significant differences were only found between the 48-W-12 and the reference site ($p = 0.006$).

The dry weight of the leaves tended to show a similar pattern to that for yield. The dry weight of the leaves of the sugar beet crop within the alley cropping system tended to be lower than that at the reference site, except for "48-W-12" treatment within the 48 m alley (Figure 3B). Significant differences for dry weight of the leaves were present among all sampling locations in the crop alley and at the control site for the 48 m alley ($p=0.02$). No significant differences were present for the 96 and 24 m alleys, $p = 0.082$ and $p = 0.119$ respectively. A multiple comparisons test comparing each sample location within the 48 m crop alley with the reference site (Dunnett's) showed no significant differences.

3.2 Effect of drought on sugar beet

Drought stressed sugar beets showed significantly smaller diameters with average values of 8 cm compared with 12 cm for non-stressed sugar beets ($p = 0.015$), and narrower cambium rings of 1.0 mm compared with 1.2 mm ($p = 0.041$) (Figure 4). The number of cambium rings was also slightly less for drought stressed sugar beets with 9 compared to 10, but this was not significant ($p=0.056$). Sugar content did not show a significant difference between drought stressed and non-stressed sugar beets with a value around 72% ($p = 0.103$).

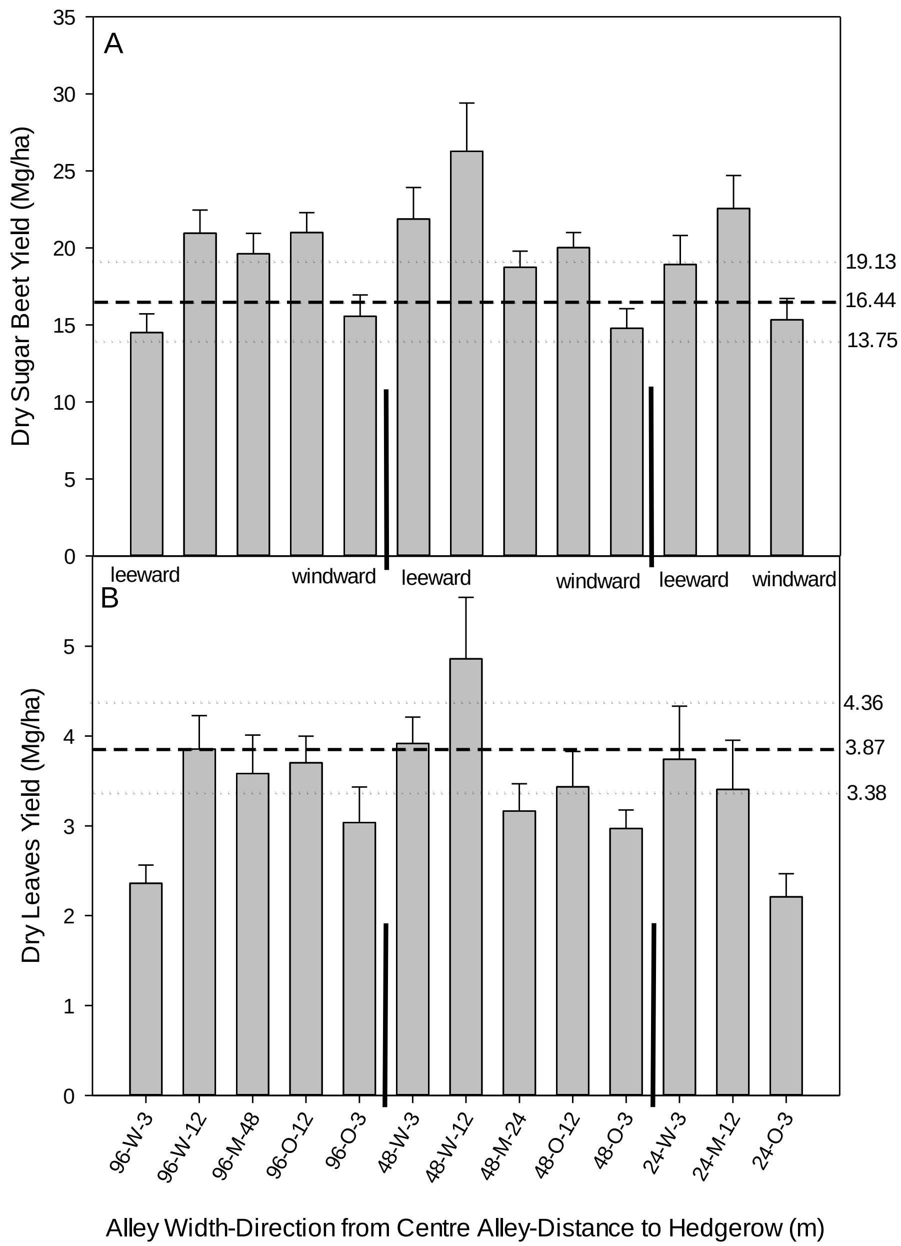

Figure 3A). Dry sugar beet yields ± SE and B) dry leaf yields ± SE for the different alley widths (96 m, 48 m, 24 m) for the Alley Cropping Research Trial for 2015 (n = 6). The horizontal dashed lines in both graphs are the mean of the reference site and the dotted lines indicate the SE of the mean.

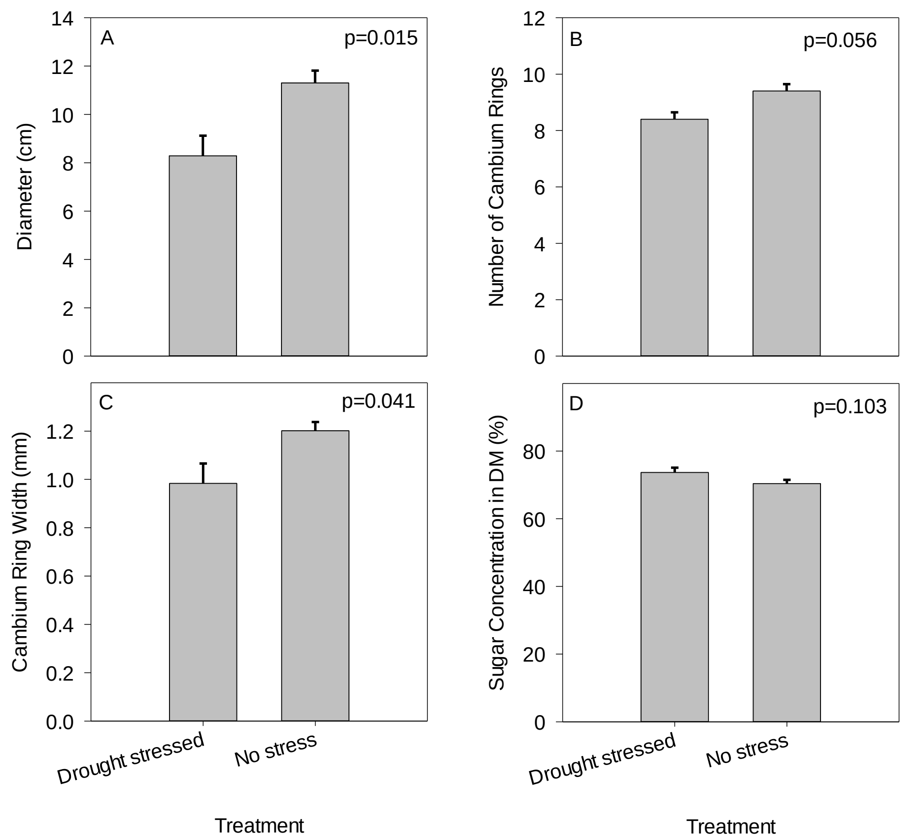

Figure 4. Different drought stress indicators ± SE for sugar beets: A) diameter of sugar beet, B) number of cambium rings, C) cambium ring width, and D) sugar concentration dry matter for the Alley Cropping Research Trial for 2015. Samples were taken from the 96 m alley from locations where the sugar beets were suffering from drought stress and from locations where they were not on 19 October 2015 (n = 5).

4 Discussion and conclusions

The tree and crop components of agroforestry systems can compete for light, water, and nutrients. During hot and dry summers, the competition for water is likely to be particularly strong. The soils at the Neu Sacro study site are loamy sands (which typically have a low available water content) and hence crops in such soils during dry periods may be predicted to suffer from drought stress and reduced leaf expansion (Bloch and Hoffmann 2005). However the presence of a high water table in most years helps to reduce some of the drought impacts. The 2015 growing season was drier than an average year, especially in May and August (Figure 2), and hence discoloration of the sugar beet leaves was observed before the end of June 2015.

Rao et al. (1998) reported that alley cropping systems can have both positive and negative effects on arable crop water availability in dry years. The provision of shelter (and shading) can reduce temperatures and evapotranspiration rates. However the trees can also compete for water and intercept rainfall. Our data (Figure 2) provides some evidence that rainfall receipts in the 24 m and 48 m alleys was lower than in the reference and 96 m alley for June and July 2015.

At the research site, the hedgerows were harvested in February 2015. Regrowth of the hedgerows from the stools started in May and maximum wind speed data showed (data not shown) that wind speed was reduced by the hedgerows from the middle of June onward. This means that during their establishment phase in May the hedgerow may have had minimal effect on the sugar beet. However during the dry spell in August, there was increased opportunity for tree-crop interactions particularly in terms of water competition. For example Gruenewald et al. (2009) reported lower soil moisture values at a distance of less than 4 m from a hedgerow. Our own data showed this trend to be strongest at the windward side (dominant winds came from the west), where wind sheltering was lower (Mirck et al., 2016).

The lower water availability in close proximity to the hedgerow was associated with low sugar beet yields at a distance of 3 m from the hedgerow (Figure 3). By contrast the higher yields often found at a distance of 12 m or greater from the hedgerow could be associated with changes in soil and air temperature and evapotranspiration (especially on the leeward side due to wind sheltering) (Gruenewald et al., 2009; Boehm et al., 2014). Mirck et al. (2016) reported higher soil moisture values on the leeward side of the hedgerow on 27 July 2015. The soil moisture content was also high on the leeward side of the 48m alley, where a high sugar beet yield was found at a distance of 12 m (Mirck et al., 2016).

Our annual sugar beet yields of 15-25 Mg ha^{-1} are comparable with non-irrigated and irrigated yields of 11-12 Mg ha^{-1} and 16-20 Mg ha^{-1} respectively in northern Germany (Bloch and Hoffmann 2005). Our leaf biomass values of 2.4-4.9 Mg ha^{-1} tended to be lower than the values of 5 Mg ha^{-1} and 6-9 Mg ha^{-1} for unirrigated and irrigated sugar beet respectively in northern Germany (Bloch and Hoffmann 2005). This difference between root and leaf yields also resulted in greater root:shoot ratios compared with the Bloch and Hoffmann (2005) study (data not shown).

Growth reductions due to drought stress can be explained in alterations of the root in growth and storage capacity (Hoffmann et al 2010). The width and number of cambium rings and total root diameter have been used as growth indicators, in addition sucrose concentration has shown a positive correlation with these indicators (Hoffmann et al 2010). The significantly smaller diameters for the drought-stressed sugar beets and their smaller cambium widths agreed with results for sugar beets grown under three different water capacities reported by Hoffmann et al. (2010). The sugar concentration in our experiment was the same for both stressed and non-stressed sugar beets, which can be explained through the results of Hoffmann et al. (2010). Hoffmann et al. (2010) reported greater sucrose concentrations under non-stressed conditions compared to stressed conditions for *wide rings*, but lower sucrose levels under non-stressed compared to stressed conditions for *narrow rings* (Hoffmann et al., 2010). This could have resulted in an average sugar concentration of wide and narrow rings to be the same for stressed and non-stressed beets.

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