Lessons learnt – Alley Cropping in Germany

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Work-package	4: Agroforestry for Arable Systems
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Approved	Paul Burgess (8 August 2017)

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1 Context

The AGFORWARD research project (January 2014 - December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at field-, farm- and landscape scales, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This report contributes to the second objective in that it contains results of the studied innovations from one of the systems being studied within work-package 4 which focuses on agroforestry for arable systems. Together with other reports, this document will contribute to Deliverable 4.11 on lessons learnt from agroforestry for arable farmers. Similar reports exist for agroforestry of high nature and cultural value, agroforestry with high value trees, and agroforestry for livestock systems.

2 Agroforestry for arable farmers in Germany

The agroforestry for arable farmers in Germany stakeholder group forms a part of a wider Participative Research and Development Network (PRDN) within work-package 4 focused on agroforestry for arable farmers. Arable agriculture provides large quantities of food, but it can be associated with reductions in soil and water quality, biodiversity, and the release of greenhouse gases. Some of these negative effects can be addressed by the integration of trees. The stakeholder group in Germany, as part of the wider PRDN, has addressed the following objectives:

I. to identify examples of the best practices, key challenges and innovations to address challenges. Tsonkova and Mirck (2014) reported the results of the initial stakeholder meeting which identified the key benefits of integrating trees with arable production as crop production and soil conservation; the key negative aspects were identified as the administrative burden, management costs, and mechanisation.
II. to agree and implement within the PRDN an experimental protocol to develop and test proposed innovations at existing experimental plots or through on-farm experiments. This was the focus of the report by Mirck and Quinkenstein (2015) who identified six technical questions related to crop yields, water and nutrient use, and the effect on wind speeds, and developed a research plan.
III. to describe and explain the key inputs, outputs and ecosystem services flows for a case study site. This was completed for the site near Forst by Mirck et al. (2015) in a system report on alley cropping in Germany.
IV. The remaining objective, which is partly addressed by this report, is to provide and promote guidelines for farmers on how to establish economically viable agroforestry practices for arable farmers.

Silvoarable agroforestry covers about 2.2 million hectares in the EU corresponding to about 0.5% of the territorial area. The largest areas of silvoarable agroforestry in the EU are found in Italy, Greece, and Spain (Den Herder et al. 2015). Agroforestry for arable farmers is not a common practice in Germany, and there are uncertainties concerning the area payment for areas including trees and a perception of the negative competitive effects of trees on crops for nutrients, water and light. However, some German farmers are interested in the use of alley cropping for woody biomass production to concurrently provide biomass feedstock and arable crops.

A major form of alley cropping examined in Germany is the integration of rows of fast growing trees, such as poplar or willow, with arable crops (Böhm 2012). It has been reported that such system can increase moisture availability for plants (Quinkenstein et al. 2009) and reduce wind velocity (Böhm et al. 2014). Since 2010, Brandenburg University of Technology Cottbus – Senftenberg has managed a 73 ha alley cropping research site near the town of Forst in East Brandenburg in Germany. The area is known for its light sandy soils that are prone to wind erosion. Therefore a potential benefit of alley cropping is to solve the erosion problem and, in addition, to provide a more resilient system in the context of climate change.

3 Objectives

Experimental plots were initially established as part of the German joint research project "AgroForstEnergie - Economic and Ecological Evaluation of Agroforestry Systems in Farming Practice", funded by the German Federal Ministry of Food and Agriculture (AgroForstEnergie 2015). The goal of this project was to study alley cropping systems, which concurrently produce a woody biomass feedstock and conventional agricultural crops. The research which focuses on soil and groundwater quality, microclimate conditions and yields of the agroforestry system relative to an adjacent area without trees, has been continued through the AGFORWARD project. The experimental work included the following objectives:

1) To determine how tree hedgerows planted at three distances (24, 48 and 96 m) affect sugar beet and winter wheat yields.
2) To monitor soil moisture content in the 15 cm topsoil layer, and sugar beet yields at different distances from the tree hedgerows.
3) To assess the effects of drought stress on sugar beet yields and sugar content.
4) To evaluate the impact of tree hedgerows on wind speed.

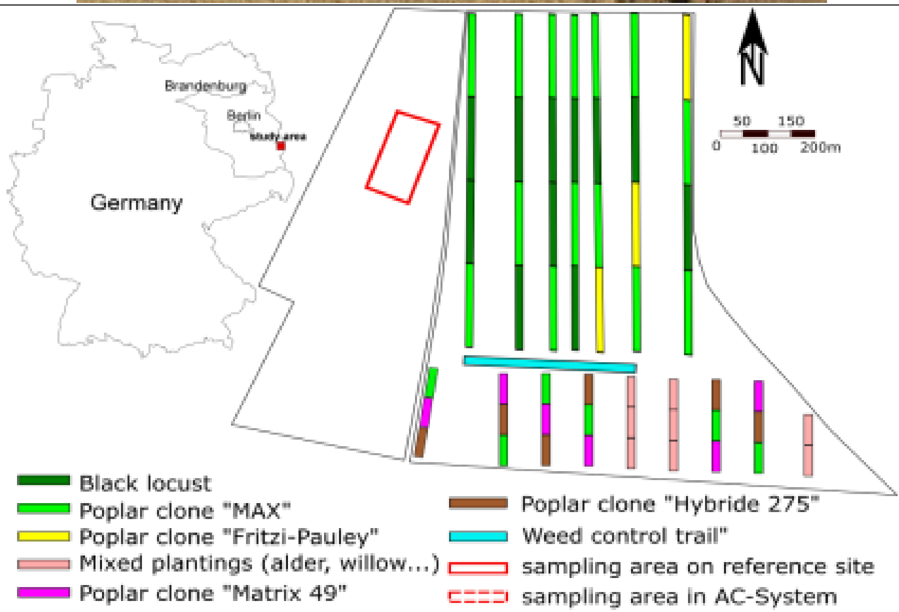
4 Methodology

The study site is located on land owned by the Forst Agricultural Cooperative in Neu Sacro close the town of Forst, in the region of Lausitz, Germany. The site includes an alley cropping system with tree hedgerows consisting of fast growing poplar and black locust managed as short rotation coppice.

During 2015, a field experiment was conducted within the alley cropping research trial (Table 1). The sugar beet crop was seeded within the crop alleys and at an adjacent conventional agricultural field in the middle of April 2015. Manual harvesting of selected sugar beets took place between 30 September and 6 October 2015. Measurements were taken in 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 where harvested in order to examine tree-crop interactions (Roa and Coe 1991). For the 96 m- and 48 m-wide crop alleys, the crop was sampled at 3 m and 12 m east and west distances from the tree hedgerows and in the centre of the alleys. For the 24 m-wide alley, crop plots were sampled at 3 m distances from the tree hedgerows and in the centre. Six replications were carried out in each treatment. Sampling plots were approximately 3 –

5 m² in size and consisted of three sugar beet rows. Prior to harvesting the sugar beet, all beets in the sampling plots were counted and the exact plot size was measured. These values were required for subsequent yield calculations. To calculate sugar beet harvests at each plot, the following protocol was used: 1) leaves and beets biomass of 12 sugar beets were harvested and weighted separately (in kg); 2) two sugar beets were collected for dry matter determination. The two beets for dry matter determination were stored in ziploc bags, transported to the laboratory and dried until a constant weight at 105°C.

Table 1. Specific description of the experiment near Forst in Brandenburg, Germany

Specific description of site	
Area	Total area 73 ha (Northern part of 40 ha was established in 2010, when black locust and poplar trees were planted. Due to the low survival rate, poplar trees were replanted in 2011; Southern part of 33 ha was established in 2014/2015)
Co-ordinates	51°47'21"N, 14°37'42"W (or : N51.789278 ; W14.628202)
Site contact	BTU contact: Michael Kanzler
Site contact email	kanzlmic@b-tu.de
Example photograph	
Map of system	 Coloured lines indicate tree rows (for species see legend). Tree species are Poplar clone 'Max' (*Populus nigra L.× P. maximowiczii*), Poplar clone Fritzi-Pauley (*P. trichocarpa*), Poplar Matrix 49 (P. maximowiczii × P. trichocarpa), Poplar Hybrid 275 (P. maximowiczii × P.) and Black Locust (*Robinia pseudoacacia*).

Climate characteristics	
Mean monthly temperature	9.3 °C
Mean annual precipitation	608 mm
Details of weather station (and data)	Data from 01/01/1981-31/01/2010 (available here) for the Forst/Lausitz weather station (id: 1400, 51°44'N, 14°38'E) (See Mirck and Quinkenstein, 2015).
Soil type	
Soil type	WRB classification: Gleyic fluvisol. Fluvisols are soils developed in alluvial deposits which are called the Latin name "*fluvius*", which means 'river' (FAO. 2001). These soils receive or have received fresh material and still show the stratification (FAO, 2015). Gleyic properties are found on soil materials saturated by ground-water during part of the year (Canarache et al. 2006).
Soil depth	approx. 2 m (until groundwater level), soil deeper
Soil texture	Loamy sands and sandy loams
Additional soil characteristics	German soil number: 45; Humus content 1.9%; Groundwater 1 – 2.5 m below soil surface. Topsoil: loamy sands; subsoil: pure sand and gravel layers, with clayey areas (Böhm et al. 2015)
Aspect	North-South orientation
Tree characteristics	
Species and variety	Poplar (*Poplar* spp.) and black locust (*Robinia pseudoacacia* L.)
Date of planting	Spring 2010 (black locust), Spring 2011 (poplar)
Intra-row spacing	0.9 m
Inter-row spacing	Double row system: 0.75 m within double row; 1.8 m between double row
Hedgerow spacing	24 m, 48 m, 96 m
Tree protection	None
Typical woodchip yield	~8 oven dry tonnes ha^{-1} $year^{-1}$ (first rotation)
Crop/understorey characteristics	
Species	Sugar beet (*Beta vulgaris*), barley (*Hordeum vulgare*) and maize (*Zea mays*), alfalfa (*Medicago sativa*)/SolaRigol (previous crop mix for potatoes), potatoes (*Solanum tuberosum*), winter wheat (*Triticum durum*)
Management	Conventional arable crop management with the usual mixture of ploughing and herbicide spraying to keep down the weeds
Typical crop yields	Potatoes : ~38 t ha^{-1}, winter wheat: 6-7 t ha^{-1}, sugar beet: ~34 t ha^{-1}
Fertiliser, pesticide, machinery and labour management	
Fertiliser	Assumed that this is modified marginally by tree hedgerows
Pesticides	Regular spraying of crops during the year to control weeds and pests
Machinery	Need for tractor access in crop alleys to allow soil preparation and spray application
Manure handling	Not necessary in field
Labour	Trees: the biomass feedstock needs to be harvested on a 3-5 year rotation; Crops: no additional labour requirements
Fencing	Not required

The effect of drought stress on sugar beet yields was measured by 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 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, the fresh weight of the circular and a perpendicular cut were measured and afterwards they were dried at 105°C until a constant weight for dry weight calculations.

In the following cropping season in 2016, when winter wheat was grown in the field, the western 96 and 48 m-wide crop alleys were sampled again. In August, manual yield measurements were taken using a metal frame of 0.25 m². For the 96 m and 48 m wide crop alleys, the crop was sampled at 3 m and 9 m east and west directions from the tree hedgerows, and in the centre of the alleys; and for the 24 m wide alley at the centre. Eight replications were carried out for each treatment. Wheat samples were transported to the laboratory and dried at 60°C for 24 hours. Dried straw and grains were manually separated, weighed with a precision of 0.01 grams, and used to derive a yield per hectare.

Additionally, in the centre of each crop alley (24, 48 and 96 m) as well as at the open field site, wind velocity was measured with cup anemometers (A100R, Vector Instruments, UK) during the 2015 and 2016 growing season. Precipitation was recorded with several aerodynamic rain gauges (ARG100, Campbell Scientific Ltd., UK). Soil moisture was measured with a Time Domain Reflectometry mobile probe (TDR) (IMKO GmbH, Ettlingen, Germany) to a depth of 15 cm on a bi-weekly basis between mid-May and the end of August 2015.

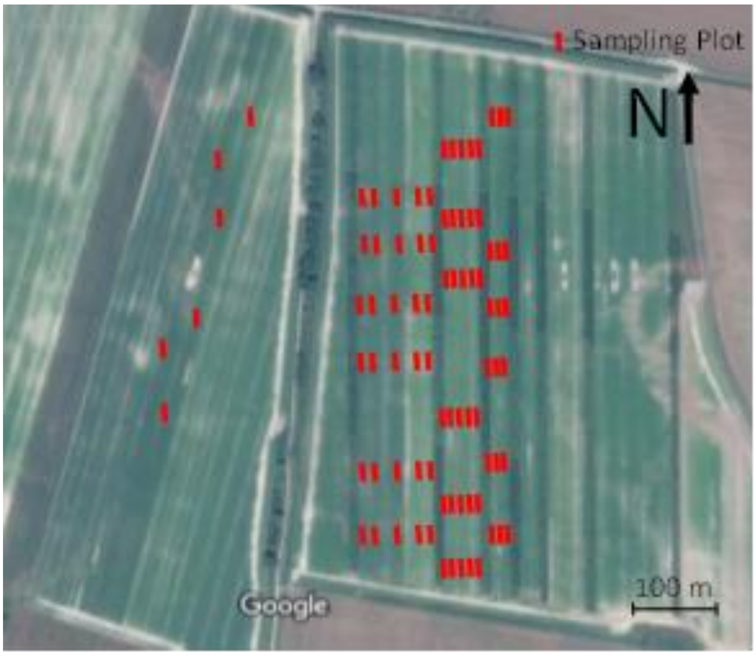


Figure 1. Map of the alley cropping research trial at the Agricultural Cooperative Forst near the town of Forst, in the region of Lausitz in Germany. Coloured squares indicate sampling plots for the manual sugar beet harvest during 2015 (map source: Google Maps). Reference: Mirck et al. (2016a).

5 Results

5.1 Crop yields

In 2015, the sugar beet yields ranged from 15 to 25 Mg ha^{-1} (Fig. 2A). Sugar beet yields tended to be reduced close to the tree hedgerow and to be increased at a distance of 12 m and in the middle of the alleys in comparison with the adjacent reference crop field. Significant differences were present between the mean yields in the five sampling points of 96 m ($p = 0.026$) and 48 m ($p = 0.004$) alleys and the reference site. Multiple comparisons (Dunnett's test) comparing each sample location within the crop alley with the reference site showed significant differences only between the 48-W-12 locations and the reference site ($p = 0.006$).

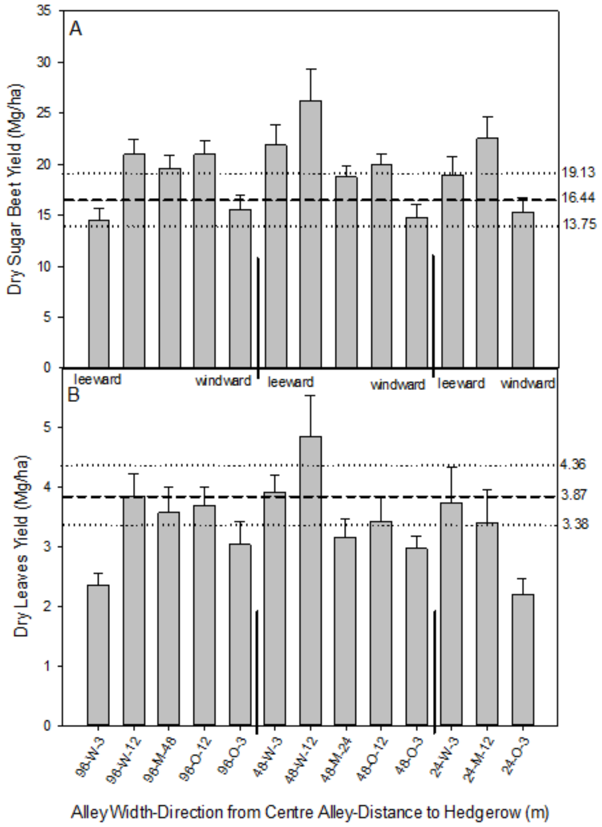


Figure 2. A) Mean dry sugar beet yields ± SE and B) mean dry leaf yields ± SE for the different alley widths (96 m, 48 m, 24 m) for the Alley Cropping Research Trial for 2015 (n = 6). The horizontal dashed lines in both graphs are the means of the reference site and the dotted lines indicate the SE of the means. Reference: Mirck et al. (2016b).

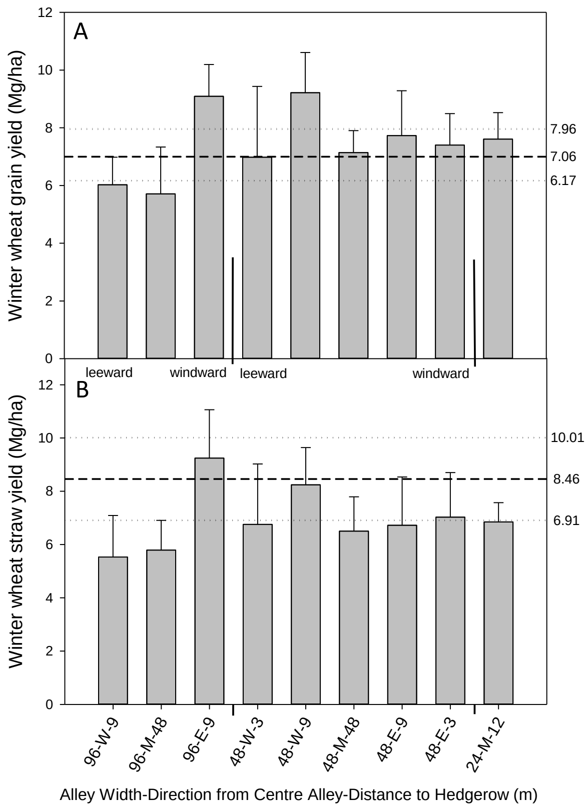


Figure 3. A) Mean winter wheat yields ± SE and B) mean straw yields ± SE for the different alley widths (96 m, 48 m, 24 m) for the Alley Cropping Research Trial for 2016 (n = 8). The horizontal dashed lines in both graphs are the means of the reference site and the dotted lines indicate the SE of the means.

Sugar beet leaf biomass ranged from 2.4 to 4.9 Mg ha^{-1} (Fig. 2B) and showed a similar pattern to the yields. The dry weight of the leaves of the sugar beet crop within the alley cropping system was significantly lower than at the reference site, except for "48-W-12" treatment within the 48 m alley, which had higher yield as at the reference site. Significant differences for the dry weight of the leaves were present between all sampling locations at the crop alleys and at the control site for the 48 m alley ($p = 0.02$). No significant differences were found 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 test) showed no significant differences.

In 2016, winter wheat grain yields varied between the reference crop site and crop alleys with the average values of 5.7 and 9.2 Mg ha^{-1}. Multiple comparisons revealed that grain yields at 96-E-9 and 48-W-9 locations at the crop alleys were significantly higher (p = 0.01 and p = 0.03) compared to the reference site (Holm-Sidak test). For the remaining sampling positions, no significant differences were detected. Straw yield at the reference site had an average value of 7.1 Mg ha^{-1}, whereas values detected within the crop alley ranged from 7.0 to 9.2 Mg ha^{-1}. Significant differences were detected between the reference site and 96-E-9 (p = 0.01) and 48-W-9 (p = 0.03) locations within the crop alleys. Yield surplus in relation to the reference site was up to 2.2 Mg ha^{-1}.

5.2 Effect of drought on sugar beet

Figure 4 reveals, that drought stressed sugar beets had significantly smaller diameters with average values of 8 cm compared to 12 cm for non-stressed sugar beets (p = 0.015), and narrower cambium rings of 1.0 mm compared to 1.2 mm (p = 0.041), respectively. The number of cambium rings was also slightly smaller 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).

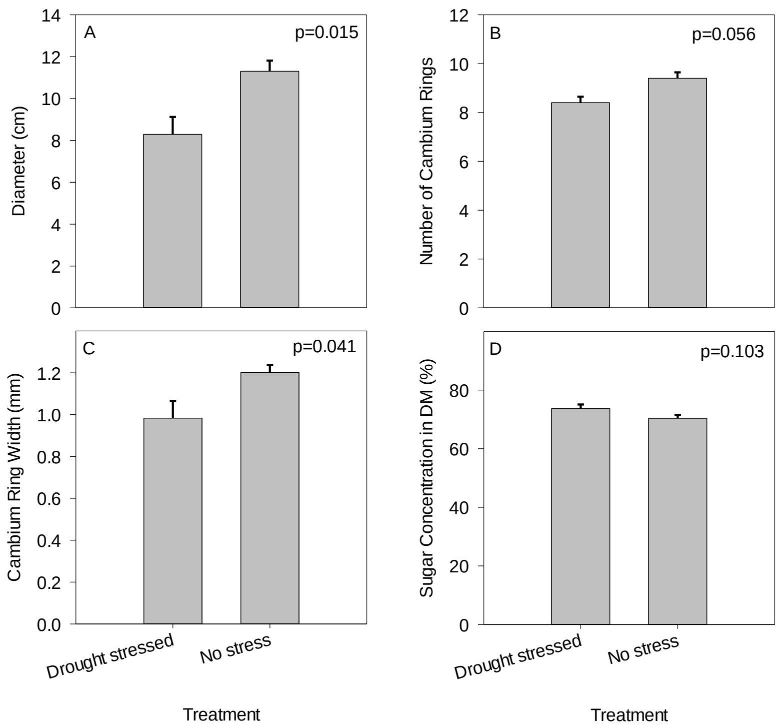


Figure 4. Different drought stress indicators ± SE for sugar beets: A) diameter of sugar beet, B) number of cambium rings, C) cambium ring width, and D) sugar concentration in dry matter for the Alley Cropping Research Trial for 2015. Samples were taken from the 96 m alley from locations where the sugar beets were suffering from drought stress and from locations where they were not stressed on 19 October 2015 (n = 5). Reference: Mirck et al. (2016a).

5.3 Rainfall and soil moisture content in topsoil layer

Detailed results are presented by Mirck et al. (2016) in the following paper: Mirck, J., Kanzler, M., Böhm, C. and Freese, D. (2016): Sugar beet yields in an alley cropping system during a dry summer. Full paper in IFSA Conference Proceedings July 2016. However some of the key findings are summarized below.

Long dry periods occurred in May, August, and between the end of September and the beginning of October 2015. For the period between May and October, the rainfall amount at the reference site was similar to that in the tree alleys, although total rainfall tended to be smaller in the 48 m- and the 24 m-wide alleys. A comparison between the monthly precipitation amounts between 1985 and 2014 time period and in 2015 growing season indicated that May and August were much drier than usual.

Soil moisture contents decreased over the course of the growing season with values between 40% and 45% during the beginning of June 2015 and as low as 20% during the end of July 2015. Significant differences in soil moisture were measured between the reference site and the 48 m alley for July 27 when taking all distances into account ($p<0.001$). For the 96 m alley, soil moisture contents were higher in comparison with the references site when only taking measurement point of 21 m or less into account (for better comparison with the 48 m alley), but these differences were not significant ($p = 0.283$). Differences between the leeward and the windward site were tested for the 96 m ($p = 0.0451$) and the 48 m ($p = 0.133$) alleys as well, but were not significant.

5.4 Wind speed reduction

Detailed information about the effectiveness of the windbreaks is reported by Böhm et al. (2014) in the following publication: "Böhm C, Kanzler M, Freese D (2014) Wind speed reductions as influenced by woody hedgerows grown for biomass in short rotation alley cropping systems in Germany. Agroforestry Systems 88(4): 579–591". These measurements have been followed up with subsequent measurements following the harvest of the tree strips in February 2015.

Between February and May 2015, the wind velocity measured at four different locations (open field, centre of 24, 48 and 96 m-wide crop alley) showed no obvious differences (data not shown). This is mainly due to the fact that the tree strips were harvested in February 2015. Trees started to resprout at the end of April, and by the end of September the poplar trees achieved an average height of 2.8 m.

Based on the measurements conducted between 1 June and 30 September 2015, daily wind velocities at the central parts of the 24, 48 and 96 m-wide crop alleys were reduced by 25, 24 and 27%, respectively, compared to the reference site (Figure 5A).

In 2016 during the subsequent growing season, this wind velocity reduction increased to 32% and 29% in the centre of the 24 and 48 m-wide crop alleys respectively (Figure 5B). The mean reduction in the centre of the 96 m alley was 21%.

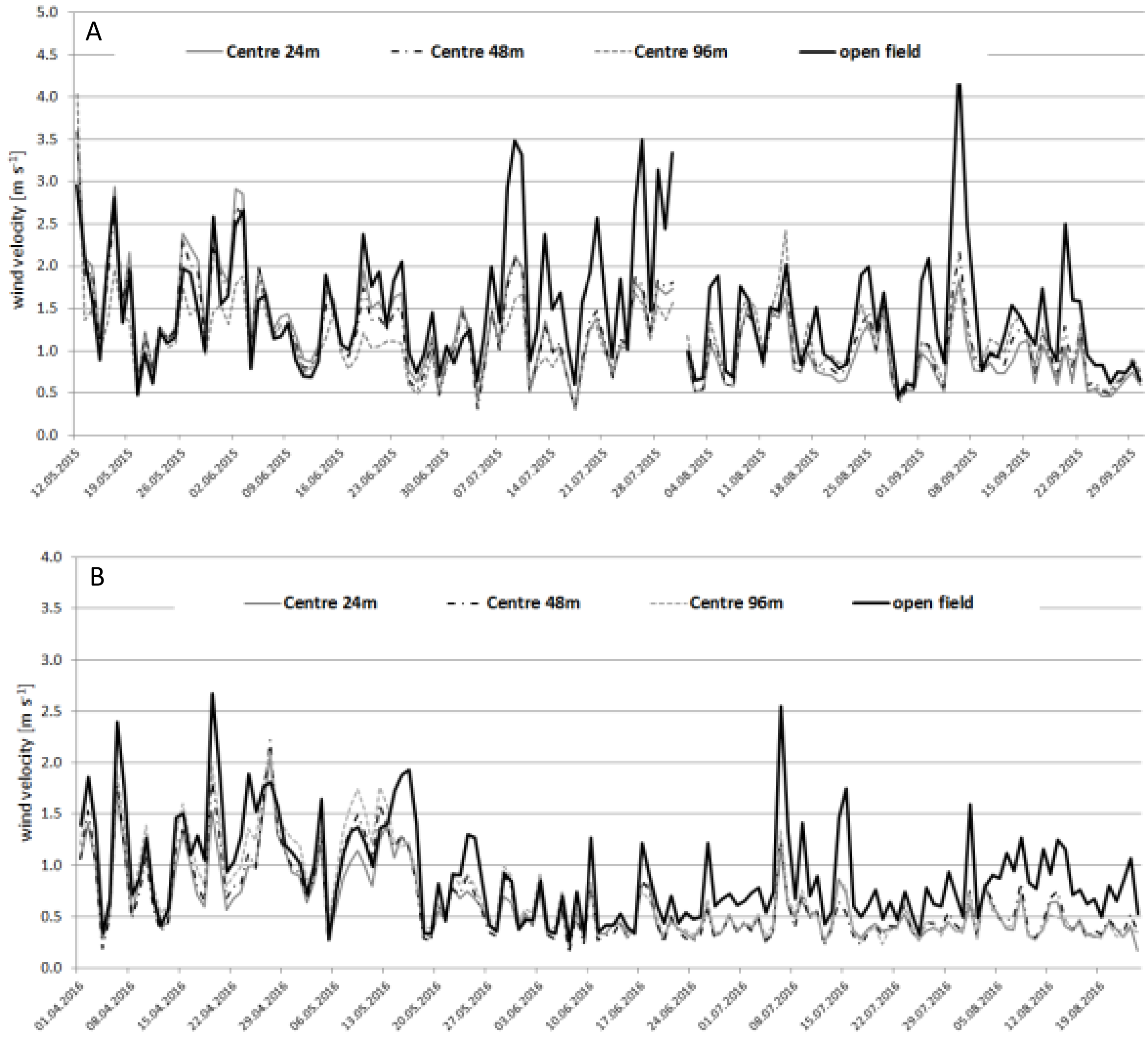


Figure 5. Daily mean wind speed measured at open area of reference site and at central parts of 24, 48 and 96 m-wide crop alleys within the alley cropping system between A) May and September 2015 and B) April and August 2016.

6 Conclusions

The principal lessons learnt from the measurements and observations in the alley cropping system with different widths of crop alleys between poplar and black locust hedgerows include:

- Sugar beet and winter wheat yields measured close to the tree hedgerows (3 m) on leeward and windward sites were usually lower than at the other locations within the alley cropping system and the open field reference site. This is probably a result of competition between the crops and the trees for light, nutrients and/or water.
- At distances greater than 9 m away from the hedgerows within the alley cropping system, sugar beet and winter wheat yields were higher than at the open field site.
- The dry weights of the leaves of sugar beet and the straw yield from the winter wheat were generally lower in the crop alleys than at the open field site.
- Drought stressed sugar beets showed significantly smaller diameters than non-drought stressed beets, but the sugar concentration remained similar.
- The soil moisture content on the leeward side close to the tree hedgerows tended to be higher than under unsheltered conditions.
- The introduction of tree hedgerows within the agricultural landscape can reduce wind velocity, and thereby diminish wind erosion.
- Although not reported here, Quinkenstein et al. (2009) and Kanzler et al. (2016) have demonstrated that reducing the wind speed can increase relative humidity and the air temperature, and thus tree hedgerows may improve conditions for plant growth.
- The above work has focused on the responses of wheat and sugar beet. Future investigations should focus on the effect of tree-strips on microclimate, water balance for a wider range of crop species and how this can be used to reduce the negative impacts of climate variability on crop yields.

7 Acknowledgements

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