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FAST GROWING TREE SPECIES IN ALLEY CROPPING SYSTEMS AND THEIR INFLUENCE ON MICROCLIMATE IN GERMANY

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ABSTRACT

The production of energy wood on arable land has been increased in Germany during the last years. In this context, agroforestry systems keep a prominent position in agriculture, since they allow the simultaneous production of energy wood and food or feed on the same field. Fast growing trees arranged in hedge structures (alley cropping) can have positive effects on microclimate.

Results of different research studies carried out in several alley cropping sites located in eastern Germany show that wind velocity can be reduced by more than 50 percent, even though tree hedgerows were not higher than four meters. The observed reduction of wind speed was depending on the distance to trees, on the orientation of tree hedges as well as on the width of the crop alleys. Potentially negative effects on crop yield were expected due to the shading the peripheries of crop alleys by trees. However, first results indicate that the reduction of the global radiation by short rotation trees did no show any negative effect on crop yield. As an exception, the crop yield on a post-mining site was evenly higher near trees compared to the center of crop alleys. In summary, the establishment of alley cropping with fast growing trees have positive effects on microclimate and hence on the yield stability of crops cultivated in between the tree hedgerows without any significantly negative impact on the recent practice of land management.

Keywords: bioenergy, black locust, crop yield, hedgerows, poplar, shadowing, short rotation, soil erosion, wind break, wind velocity

INTRODUCTION

Cultivation of energy crops is increasingly gaining importance against a background of the stronger focusing on renewable energy sources in Germany (Fachagentur Nachwachsende Rohstoffe 2013a). In this context, bioenergy provided by woody biomass is still the most important form of renewable energy (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2010). Because of the increasing demand for energy wood during the last years, cultivation of fast-growing trees on agricultural sites was expanded perceptibly in Germany (Fachagentur Nachwachsende Rohstoffe 2013b). Mostly, cultivation of fast-growing trees takes place in the form of short rotation coppices. Alley cropping systems, however, represent a promising possibility to cultivate woody crops as well. This type of agroforestry is currently progressing in Germany, due to the fact that conventional crops and trees for bioenergy can be produced simultaneously on the same field without to restrict established management practices or existing technical equipment.

Generally, microclimate of arable land is influenced by tree rows planted in close distance to crop fields. Such modifications of microclimatic parameters can be mainly assessed as beneficial for the growth performance as well as the yield of crops cultivated on adjacent fields (e.g. Pretzschel *et al.* 1991). Especially in terms of shelterbelts there is a quite large amount of research studies that dealt with tree rows and their effect on the wind velocity (e.g. Nuberg 1998). Significantly less investigated is the question of how such changes may be transferred to short rotation hedgerows of alley cropping systems. Due to the usually short rotation periods of three to six years average height of these tree hedges is comparatively low and varies commonly between three and eight meters. Furthermore, tree hedgerows are harvested periodically, and hence, lose temporarily their protective effect. Shadowing effects of trees and their influence on crop yield represent another important issue that should be investigated in more detail for short rotation alley cropping systems.

The primary objective of this study was to quantify the influence of relatively small tree hedgerows within short rotation alley cropping systems in the temperate region on selected microclimatic parameters including wind velocity and global radiation on the basis of multiannual high temporal resolution measurement series. In addition the influence of the arrangement of tree hedges (e.g. distance between hedgerows, orientation of stripes) on microclimate was also part of this study and finally the meteorological data were related to the crop yield depending on the varied distance from hedgerows.

MATERIALS AND METHODS

Study sites

Investigations were carried out at two sites that are situated in Southern Brandenburg State, Germany, about 150 km southeast of Berlin. The study area is characterised by an average annual precipitation sum of 560 mm and a mean annual temperature of 9.3 °C (1951-2003, meteorological station Cottbus). Both sites are part of a broad, mainly flat and less structured landscape.

Site I is located in the post-mining area of the lignite opencast mining “Welzow-Süd” and encompasses an area of almost 18 ha. This site is characterized by humus- and nutrient-poor sand-dominated dump substrates. The establishment of the alley cropping system occurred in spring 2007 using one-year-old, bare-rooted seedlings of black locust (*Robinia pseudoacacia*). Trees were planted in hedgerows consisting each of four double rows, which 1.8 m away from each other (plant density: 9200 trees per hectare wood area). The distance between hedgerows is 12 and 24 m, respectively. Hedgerows are oriented in north-south direction on about 50 % of the area, whereas the other half was planted in east-west direction. After five years of growth (mean tree height: 3.75 m) each second hedgerow was harvested completely. Alfalfa (*Medicago sativa*) was cultivated on crop alleys during the first four years. The crop rotation has been continued with spring barley (*Hordeum vulgare*), oat (*Avena sativa*) and winter rye (*Secale cereale*).

Site II is farm land at a naturally formed area of land close to the river “Neiße” and was used for agriculture for several decades. The alley cropping system was established on 40 ha in spring 2010. Hedgerows are composed of four double rows of black locust and poplar clones “Max”

(*Populus maximowiczii x Populus nigra*) and "Fritzi Pauley" (*Populus trichocarpa*) that were planted as one-year-old, bare-rooted seedlings and cuttings, respectively. The plant density was around 8700 trees per hectare woodland. Trees were not harvested before. Hedgerows are oriented in north-south direction. The distance between hedgerows varies between 24, 48 and 96 m. Crop alleys were cultivated with lupine (*Lupinus* spec.) and potatoes (*Solanum tuberosum*) during the period of measurement.

Microclimatic parameters

Meteorological data were collected by means of weather stations that were placed in different distances to the tree stripes. Data were measured every 10 minutes in 1 m above soil surface and recorded using data loggers (Delta-T devices). To guarantee comparability, temporary data losses occurred due to technical problems at one weather station were assumed for all stations within the same site.

At site I climate data were recorded from June 2008 until spring 2013, while at site II weather data were measured from April 2012 on. Altogether four weather stations were installed a site. Following meteorological parameters were measured at these stations: wind velocity, air temperature, relative air humidity, global radiation, precipitation. Furthermore, soil moisture and soil temperature were measured continuously in different soil depths.

At each site, one of these stations was installed on an adjacent open field (Site I REF and Site II REF), which each acts as reference area for the alley cropping systems. The remaining three weather stations at site I were built up on a north-south oriented, 24 m wide crop alley. One was installed at the center of this alley (Site I CENTER 24m), one 2 m away from trees at the western (Site I 2m-WEST 24m) and the last station 2 m away from trees at the eastern (Site I 2m-EAST 24m) edge area. Additionally, one anemometer was installed at the center of an east-west oriented, 24 m wide crop alley in January 2012 (Site I CENTER 24m EW). At site II three meteorological stations were built up on a 96 m wide crop alley. Analogous to site I, one station was placed at the center (Site II CENTER 96m) and one 3 m away from trees at the western side (Site II 3m-WEST 96m). The fourth station here was installed at the western edge area as well, about 23 m away from the hedgerow (Site II 23m-WEST 96m). In addition to these stations three further anemometers were installed at site II in June 2012. One of that was placed 3 m away from trees at the eastern side of a 96 m wide crop alley (Site II 3m-EAST 96m). The others were built up at the center of a 24 m and a 48 m wide crop alley, respectively (Site II CENTER 24m and site II CENTER 48m).

Crop yield

Determination of crop yields was carried out using the partial harvest method on the 24 m wide, north-south oriented crop alleys at site I depending on the distance to hedgerows. For that, the complete aboveground biomass was sampled at squares of 1x1 m. Three of such sampling points were established at each of eight crop alleys. One was placed at the center and the others 3 m away from tree hedges at the western and eastern edge areas, respectively. Samplings were carried out in summer 2010 (alfalfa) and 2012 (oat) before the harvest.

RESULTS

Meteorological data

In the following, only the meteorological parameters wind velocity and global radiation are considered. For site I climate data are given as annual averages for the years 2009 to 2012, while for site II the average has been calculated for the measurement period from July 2012 until the end of April 2013. The data from the alley cropping systems were compared to measured values of the reference stations, which were set to 100 %.

On crop alleys at site I the mean wind velocity from 2009 to 2012 amounted to 1.1 m s^{-1}, while in the same time period this was nearly twice as high at the adjacent open field (Table 1). Generally, the windbreak effect increased with increasing tree height until the end of 2011. A moderate increase of wind velocity was observed after the harvest of each second hedgerow in winter 2011/2012. The highest windbreak impact was observed in the western edge area (leeward side) of the north-south oriented crop alleys, where the wind velocity was reduced by almost 60 %. In the center of the crop alleys at site I the reduction of wind velocity still amounted to 54 % compared to the reference field, although the average high of the five years old trees was only 3.75 m before the harvest in winter 2011 (Table 1). The wind reducing effect was considerably lower when tree hedges were planted not towards the prevailing wind direction. In 2012, the wind velocity was only 25 % lower in the center of the east-west oriented crop alleys, while in the center of the north-south oriented alleys the velocity of the west dominant winds was reduced by almost 44 % compared to the open field (Table 1).

Table 1: Annual averages of wind velocity for the years 2009 to 2012 and their relations to the reference values (open field) expressed as percentage at site I

Weather station	2009		2010		2011		2012	
	[m s^{-1}]	[%]	[m s^{-1}]	[%]	[m s^{-1}]	[%]	[m s^{-1}]	[%]
Site I CENTER 24m EW	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.4	74.6
Site I 2m-WEST 24m	1.3	65.5	0.9	50.3	0.9	40.1	0.9	48.4
Site I CENTER 24m	1.5	77.4	1.2	61.8	1.0	45.9	1.0	56.3
Site I 2m-EAST 24m	1.5	76.0	1.1	60.6	1.1	53.0	n.d.	n.d.
Site I REF	1.9	100.0	1.9	100.0	2.2	100.0	1.8	100.0

n.d. = not determined

On the reference field without trees of site II the average wind velocity amounted to 1.8 m s^{-1} at site II, whereas the mean wind velocity of the 96 m wide crop alley three years after planting of the tree hedgerows varied between 1.0 and 1.7 m s^{-1}. Here, the highest windbreak effect was also observed at the western edge area (Table 3). Despite the relatively low average tree height of 3.15 m, the wind reducing effect still amounted to 6 % at the center of the 96 m wide crop alleys. Generally, the windbreak effect increased significantly with decreasing width of crop alleys. Thus, the wind velocity has been reduced by 49 % compared to the open field at the center of the 24 m wide crop alleys (Table 3).

At site I, no reduction of global radiation occurred during the whole period of investigation at the center of crop alleys. However, an increasing shadowing leading to a decrease of the global radiation has been ascertained at their peripheries (Table 2). In 2011, the average decline of the global radiation amounted to more than 10 % at the eastern edge area and even almost 30 % at the western side that included an area at a distance of up to 3 to 4 m from tree stripes. After the harvest of the hedgerows adjacent to the western periphery of crop alleys the re-sprouted trees caused a reduction of the global radiation, on an annual average, of about 7 % compared to the open field (Table 2).

Table 2: Annual averages of global radiation for the years 2009 to 2012 and their relations to the reference values (open field) expressed as percentage at site I

Weather station	2009		2010		2011		2012	
	[W m²]	[%]	[W m²]	[%]	[W m²]	[%]	[W m²]	[%]
Site I 2m-WEST 24m	116.2	93.1	105.7	81.4	91.9	70.5	117.9	93.3
Site I CENTER 24m	123.3	98.8	129.3	99.5	131.2	100.8	126.8	100.4
Site I 2m-EAST 24m	117.4	94.1	117.1	90.1	116.3	89.3	103.2	81.7
Site I REF	124.8	100.0	129.9	100.0	130.3	100.0	126.3	100.0

At site II there was a similar trend in global radiation compared with site I. No interference was observed on the radiation intensity at the center of the 96 m wide crop alleys as well as at 13 m away from tree hedges. A radiation deficiency has been shown only directly adjacent to the hedgerows (Table 3). The comparatively lower shadowing effect at site II could be explained by the fact that the weather station placed on the western edge area was installed about 1 m further away from the hedgerow than at site I.

Table 3: Annual averages of wind velocity and global radiation for the measurement period July 2012 until the end of April 2013 and their relations to the reference values (open field) expressed as percentage at site II

Weather station	Wind velocity		Global radiation	
	[m s^{-1}]	[%]	[W m²]	[%]
Site II 3m-WEST 96m	1.0	58.6	94.5	95.2
Site II 23m-WEST 96m	1.5	81.7	108.2	109.0
Site II CENTER 96m	1.7	94.3	104.2	105.0
Site II 3m-EAST 96m	1.4	76.0	n.d.	n.d.
Site II CENTER 24m	0.9	51.0	n.d.	n.d.
Site II CENTER 48m	1.2	70.2	n.d.	n.d.
Site II REF	1.8	100.0	99.2	100.0

n.d. = not determined

Crop yield

Yield differences depending on the distance from hedgerows were determined for alfalfa as well as for oat. Generally, higher yields were observed at the periphery of the 24 m wide crop alleys at site I. The surplus at edge areas related to the center of crop alleys amounted to between 12 % (west side) and 19 % (east side) for alfalfa and between 15 % (grain, west side) and 39 % (grain, east side) for oat (Table 4).

Table 4: Yields of alfalfa (*Medicago sativa*) and oat (*Avena sativa*) depending on the distance to the tree hedgerows at site I in 2010 and 2012, respectively (n = 8)

Location at 24 m wide crop alley	Alfalfa (harvested 2010)	Oat (harvested 2012)	
		Straw	Grain
	[t ha^{-1}]		
West side, 3 m away from hedgerows	4.2	2.8	2.7
Center of crop alley	3.8	2.3	2.3
East side, 3 m away from hedgerows	4.5	3.0	3.3

DISCUSSION

Due to the reduction of wind velocity direct, physical damages to crops (Cleugh *et al.* 1998) as well as indirect negative effects such as soil erosion (Kort 1988) or an increased soil drying by wind (Unger *et al.* 1991) can be depleted considerably. Generally, there are several recent studies which focus on windbreak effects by shelterbelts. In this context, the influence of factors such as tree height or porosity was investigated in model approaches as well (Cleugh 1998). In most cases, however, shelterbelts are tree hedges higher than 5 m. Thus, results of these studies are only of limited suitability for the description of shelterbelt effects at low hedgerows which are typical for short rotation alley cropping systems. As the findings from this study show, such land use systems with tree heights of usually less than 5 m can lead to a significant decrease of wind velocity as well. Furthermore, the fact that tree stripes arranged one after another may result in a large-scale reduction of wind velocity (Kurz *et al.* 2001) indicates to the possibility to decline the wind erosion potential in extensive agricultural landscapes due to the establishment of short rotation alley cropping systems.

According to Nuberg (1998) the area of maximum shelter is usually between four and twelve times the height of trees, while the wind velocity is less reduced directly adjacent to the hedgerows. If this, for example, is assumed for site II, then only the center of the 48 m wide crop alley would be located in the maximum sheltered zone. However, this is contrary to the results presented in this study, which show for short rotation alley cropping systems that the wind velocity is lowest at the edge areas of crop alleys and that the wind reduction increases with decreasing distances between hedgerows. Although the average reduction of wind velocity was lower, wind peaks were attenuated significantly also at the center of the 96 m wide alleys (data not shown). This fact is particularly important in terms of the avoidance of wind erosion. Additionally to the width of crop alleys the orientation of the hedgerows had a significant influence on the wind velocity. This is consistent with statements by (Brandle *et al.* 2004). In order to guarantee the maximum shelter effect short rotation hedgerows should be orientated against the prevailing wind direction.

Wind-related soil drying can play a central role especially at extensive, unstructured landscapes. In such areas to which also belongs the study region, the drying-out potential of agriculturally used soils can be decreased and thus the water availability for crops enhanced due to the reduction of wind velocity (Böhm *et al.* 2011). At site I, which can be assessed as susceptible to drought stress, highest crop yields were determined at the edge areas of crop alleys. This is contrary to investigations by Varella *et al.* (2011) or Ding and Su (2010). According to these authors crop yields are often lower near trees (mostly between once and twice the height of trees) due to competition effects. However, water availability is one of the most important yield limiting factors at site I. Therefore, it can be assumed that the water availability was higher at edge areas compared to the centers of crop alleys. This is still supported by the fact that yields were higher at edge areas despite the lower radiation intensity. The comparison of yields (Table 4) and global radiation (Table 2) shows that the reduced global radiation had no negative effect on the crop yield. Rather, highest oat yields, for example, were determined at most shadowed areas in 2012. Thus, the decrease of radiation intensity due to the interspecific competition appears to be less important than the potentially lower evapotranspiration rate caused by the shadowing. This is consistent with findings by Surböck *et al.* (2005) or Seiter *et al.* (1999), who determined higher yields at edge areas as well. Hence, the attenuation of radiation cannot be seen as negative at site I. However, especially for sites with sufficient water supply during the vegetation period, a certain depression of crop yield due to competition with trees cannot be excluded. Additionally, crop species respond differently to the competition with tree hedgerows (Kort 1988). Intensity as well as quality of changes in microclimate caused by short rotation tree hedgerows depends considerably on site conditions. Therefore, a generalization of microclimate effects in short rotation alley cropping systems seems to be hardly possible.

CONCLUSIONS

Short rotation alley cropping systems result in changes of microclimatic parameters compared to open fields without trees, leading to more favorable conditions for crops. Especially, tree hedges consisted of short rotated fast growing tree species represent an effective windbreak referring to their comparatively low height. Consequently, short rotation alley cropping systems serve for the supply of woody biomass for bioenergy and contribute simultaneously to an enhancement of the microclimate. Furthermore, there is an indirect positive impact on soil fertility and partly on the average crop yield. This fact appears to be particularly relevant for extensive agricultural landscapes at the temperate region.

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