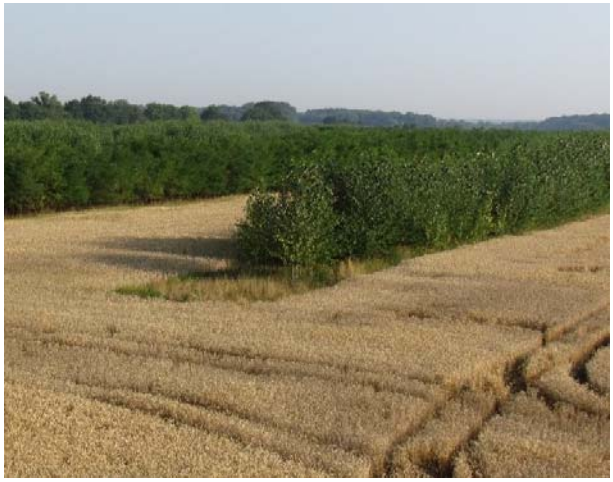

Research and Development Protocol for Alley Cropping in Germany

Project name	AGFORWARD (613520)
Work-package	4: Agroforestry for Arable Farmers
Specific group	Alley Cropping Systems in Germany
Milestone	Milestone MS16 (4.3) Part of Experimental Protocol for WP4
Date of report	9 March 2015
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Approved	27 April 2015 Paul Burgess

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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 a field-, farm- and landscape scale, 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. It contributes to the initial research and development protocol, Milestone 16 (4.3), for the participative research and development network focused on the use of agroforestry in arable systems.

2 Background

Agroforestry for arable farmers is not common practice in Germany. However alley cropping for woody biomass production is of interest in the country due to its high potential to concurrently provide biomass and arable crops. At an experimental level one of the systems that exists in Germany is the integration of rows of fast growing trees, such as poplar or willow, with arable crops.

The experiment is 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.

A meeting of the Alley Cropping Systems in Germany stakeholder group was held on 28 August 2014 (Tsonkova and Mirck 2014). During this meeting a list of possible innovations was developed. These innovations will be addressed at the agroforestry system research site close to Forst, Germany:

- Assessing competition between crops and trees for light, water and nutrients
- Compare productivity in agroforestry and conventional agricultural systems
- Assess erosion reduction in agroforestry systems and optimize spatial arrangement of hedgerows
- Improve marketing and branding of agroforestry products

3 Objective of experiments

The aim of the experiments is to assess competition between crops and trees for light, water and nutrients in different spatial designs. Key questions include:

- How does agroforestry affect crop yield?
- What is the tree root distribution and how do tree roots interact with crop roots during the vegetation period?
- How does agroforestry affect water use efficiency?
- How does agroforestry affect nutrient cycling?

- How does agroforestry affect soil health and litter quantity and quality?
- How does hedgerow design affect wind speed, soil moisture, relative humidity and air temperature?

In relation to these questions, a number of hypotheses can be developed:

- Agroforestry improves crop and overall yield.
- Tree roots are present in lower soil layers than crop roots resulting in greater water and nutrient capture and efficiencies.
- Soil health and litter quantity and quality will be improved by hedgerows.
- Hedgerow spacing affects wind speed, soil moisture, relative humidity and air temperature.

4 System description

The trial will take place in a 73 ha alley cropping system located at the Agricultural Cooperative Forst in close proximity of the town of Forst (51°47'21" N, 14°37'42" W) (Figure 1; Table 1), and located at about 800 m away from the river Neiße. The research site is an alley cropping system. The northern part of the alley cropping system is 40 ha and consists of poplar (*Poplar* spp, varieties Max 1 (*Populus nigra L.× P. maximowiczii*) and Fritzi-Pauley (*P. trichocarpa*) and black locust (*Robinia pseudoacacia*). This part of the experimental site was planted in 2010 and the poplars were replanted in 2011. The system consists of seven tree hedgerows that are 11 m wide (four double rows) and 600 m long. The distance between the tree hedgerows varies between 24, 48 and 96 m. The southern part of the alley cropping system is 33 ha and was planted in 2014 and 2015. It consists of six hedgerows of poplars that are 17.4 m wide and three hedgerows of mixed planting of alder (*Alnus glutinosa*), ash (*Fraxinus excelsior*), and willow (*Salix spp.*). The distance between the tree hedgerows varies between 72, 120 and 144 m. Further details are given in Table 1.

Figure 1. Looking North-South along the tree rows with poplar and winter wheat in the alleys (source: Dirk Freese, summer 2014).

Table 1. Description of the site, with soil, tree, understorey, livestock, and climate characteristics.

Site characteristics	
Area (ha):	73 ha (Northern part 40 ha, established in 2010 and poplars replanted in 2011; Southern part 33 ha, established in 2014/2015)
Co-ordinates:	51°47'21"N, 14°37'42"W (or : N51.789278 ; W14.628202)
Site contact:	BTU contact: Jaconette Mirck
Site contact email address	jmirck@gmail.com

Soil characteristics	
Soil type (WRB classification)	Gley-Vega and Pseudogley-Vega
Soil depth	
Soil texture (sand%, silt%, clay%)	loamy sands and sandy loams
Additional soil characteristics	German soil number : 45; Humus content 1.9%; Groundwater 0.8 – 2.3 m below soil surface

Tree characteristics		
System	Agroforestry system	Reference system*
Tree species	Poplar (*Poplar* spp) and black Locust (*Robinia Pseudoacacia*)	None
Variety/rootstock	Poplar varieties: Max 1 and Fritzi-Pauley and black Locust (*Robinia Pseudoacacia*)	None
Tree density (spacing)	8715 trees/ha (between double rows: 1.8 m; within double rows: 0.75 m; within rows: 0.9 m)	None
Tree protection	None	None
Additional details		

Crop characteristics		
System	Agroforestry system	Reference system*
Species	Sugar beet (*Beta vulgaris*), barley (*Hordeum vulgare*) and maize (*Zea mays*)	Sugar beet (*B. vulgaris*), barley (*H. vulgare*) and maize (*Z. mays*)
Coverage	Complete	Complete
Additional details	Previous years: maize (*Z. mays*), maize (*Z. mays*), alfalfa (*Medicago sativa*)/SolaRigol (legume and not legume mix for potatoes), potatoes (*Solanum tuberosum*), winter wheat (*Triticum durum*)	Previous years: maize (*Z. mays*), maize (*Z. mays*), alfalfa (*M. sativa*)/SolaRigol (legume and not legume mix for potatoes), potatoes (*S. tuberosum*), winter wheat (*T. durum*)

Climate data	
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)

* To which the agroforestry system is compared

5 Experimental design

5.1 Conceptual design

The primary goal of the research study is to measure yield differences between alley cropping and conventional agricultural systems. The treatments are described in Table 2.

Table 2. Description of treatments

Treatment A	Treatment B	Treatment C	Treatment D
Alley cropping	Alley cropping	Alley cropping	Conventional agriculture
Tree: poplar	Tree: black locust	Crop: sugar beet	Crop: sugar beet

5.2 Description of design

A map of the Agricultural Cooperative Forst field site is shown in Figure 2. This research study will focus on the most northern 20 ha of the northern part. In this part of the alley cropping system the tree hedgerows consist of double rows of poplar (variety Max 1) and black locust.

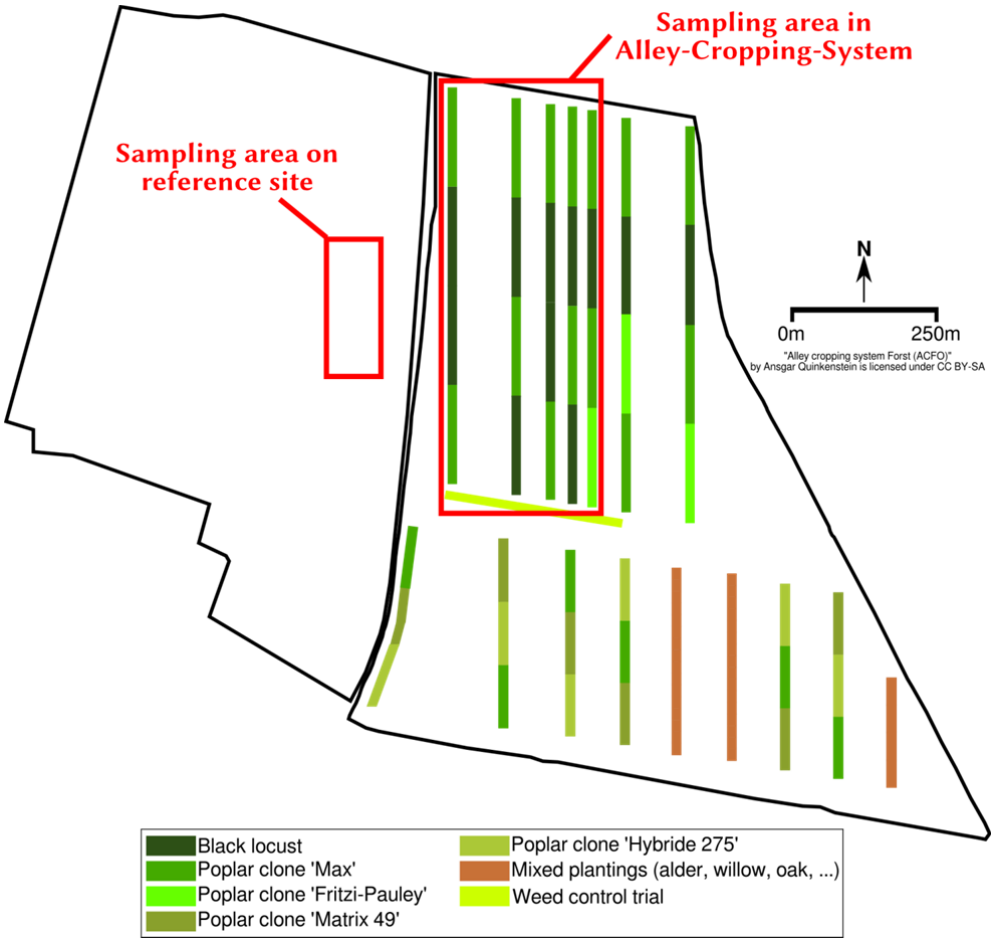

Figure 2. Map of the Agricultural Cooperative Forst field site. Coloured lines indicate tree rows (for species see legend). Tree species are Poplar clone 'Max' (*Populus nigra L.× P. maximowiczii*), Poplar clone Fritzi-Pauley (*P. trichocarpa*), Poplar Matrix 49 (*P. maximowiczii × P. trichocarpa*) and Poplar Hybrid 275 (*P. maximowiczii × P.*) and Black Locust (*Robinia pseudoacacia*).

Tree measurements will take place in four black locust and four poplar plots. Crop measurements will concentrate on the four western crop alleys of the alley cropping system, which will be planted with sugar beet (*Beta vulgaris*) and a 50 m wide strip planted with sugar beet in the reference field. It was impossible for the farmer to plant the total area with sugar beet, because German legislation allows the farmers to plant a total of 30 ha. As a result the remainder of the alley cropping system will be seeded with maize (*Zea mays*) and the reference field with barley (*Hordeum vulgaris*).

6 Measurements

The planned measurements to be taken in the two treatments are described in Table 3.

6.1 Yield measurements

Measuring yield for tree plots

- Previously established allometric equations for both poplar and black Locust will be used. These equations established the relationship between diameter and dry weight. Separate allometric equations were established for both centre and border row trees.
- Diameter measurements for tree measurement plots will be carried out in both four poplar and four black locust measurement plots on an annual basis.

Measuring yield for crop plots

- Within the alley cropping system crop sampling plots will include plots in close proximity to the tree hedgerows and in the centre between the rows (Rao and Coe 1991). The crop sampling will be concentrated on the north-western part of the alley cropping system and on the reference site. Sugar beet will be planted at both locations. Within the alley cropping system a grid system will be used to guarantee stratified sampling, i.e. the inclusion of both plots in close proximity to the trees and in the centre of the alleys. For the reference site, four crop plots will be sampled.
- Above and below ground biomass in these plots will be harvested using a grid across the crop area. Sub-plots of 1 m x 1 m will be harvested from about one-third of the area (Williams and Gordon 1995; Reynolds et al 2007).

Determination of land equivalent ratio

The land equivalent ratio (LER) is the ratio of the area needed under sole cropping to the area of intercropping at the same management level to obtain a particular yield (Mead and Willey 1980). For agroforestry systems it can be calculated as:

$$LER = \frac{Tree\ agroforestry\ yield}{Tree\ monoculture\ yield} + \frac{Crop/livestock\ agroforestry\ yield}{Crop/livestock\ monoculture\ yield}$$

For the calculation of the LER the above described tree and crops yields for the agroforestry and reference site will be used to calculate productivity of both agricultural systems.

6.2 Measuring root competition

- Root cores will be taken both in the tree plots (at least one core per plot) and at several distances to the hedgerows in transects across the 96 m (maximum alley width) crop alleys for black locust in the summer of 2015 (black locust trees are one year older than the poplar trees/ black locust roots are easy distinguishable from crop roots). When time allows the same will be repeated for poplar in 2016.
- The root cores will be taken to a depth of 90 cm and analysed as 15 cm sections.
- The soil cores will be washed with water, crop, tree coarse and fine roots (<2 mm) will be separated, dried and weighed.

6.3 Measuring water use efficiency

- Microclimate data such as air temperature, relative humidity, wind speed, and photosynthetic photon flux density will be used. Vapor pressure deficit will be calculated using relative humidity (Mirck and Volk 2010).
- Soil moisture percentage will be measured using a TRIME Time Domain Reflectometry (TDR) soil moisture probe in the tree plots and for the crop using same grid system as for the crop yield measurements across the crop alleys and in the four reference crop plots.
- Soil physical properties such as water retention (available water capacity), field penetration resistance, and bulk density will be characterized for a subset of these measurement plots (Brady and Weil 2002; Gugino et al 2009).

6.4 Nutrient cycling

- Soil samples will be collected from the eight tree plots, at distances of 3 and 6 m from those tree plots in both the lee and windward directions, the alley centres and the reference site. These will be analysed for major nutrients (NPK) and C and if expedient also for lignin and carbohydrate ratios.
- Nutrient data from the leaf litter study will be used (see below).

6.5 Measuring soil health/litter quantity and quality

- Litter fall will be measured for the eight tree plots and at distances of 3 and 6 m from those tree plots within the crop alleys.
- Soil organic matter, mineralizable N, aggregate stability, active carbon and hot-water C (HWC) will be measured for each of these eight tree plots, at 3, 12 m distances from these tree and in the centre of the crop alleys.
- Leaves will be collected for litter bag experiment.
- Litter bags will be placed within each of the eight tree plots to measure leaf litter decay rates.
- Major nutrients (NPK) and C, organic chemical composition of the leaf litter, or the content of cellulose, hemicelluloses, lignin and tannins, will be determined using ^{13}C solid-state Nuclear Magnetic Resonance (NMR) spectroscopy with cross polarization with magic angle spinning (CPMAS) (Kinchesh et al 1995; Baldock et al 1997).

6.6 Optimization of agroforestry system hedgerow design

- A potential optimization of the agroforestry system hedgerow design will be conducted by assessing effects of the hedgerow spacing on crop yield and on microclimatic conditions within the agroforestry system. For this purpose microclimatic measurements will be used.

Table 3. List of measurements to be taken in the four treatments

Treatments A and B: Alley cropping trees (Poplar and black locust)	Treatment C: Alley cropping crop	Treatment D: Reference crop
Diameter measurements for plot yield	Above and below ground yield	Above and below ground yield
Root cores, weight roots	Root cores, weight roots	
Soil moisture	Soil moisture	Soil moisture
Soil physical properties	Soil physical properties	Soil physical properties
Soil nutrients (NPK and C)	Soil nutrients (NPK and C)	Soil nutrients (NPK and C)
Leaf litter fall	Leaf litter fall (3, 6 m)	
Leaf (litter) nutrients (NPK and C)		
SOC, Nmin, Aggregates, HWC	SOC, Nmin, Aggregates, HWC	
Litter decay		
Weather data	Weather data	Weather data

7 Biophysical modelling

The second part of this protocol describes attempts to model the system using the YieldSAFE biophysical model. The YieldSAFE model has previously been parameterised for alley cropping systems (van der Werf et al. 2007). The alley cropping systems in Germany are different from those used to parameterise YieldSAFE; the hedgerows consist of multiple row short rotation coppice stands instead of single row high value trees.

The modelling component will have two objectives:

- Validation of the existing poplar growth model and additional parameterisation as required.
- Parameterisation of the short rotation system.

To facilitate the modelling activities additional parameters such as leaf area, height, diameter, and above ground biomass consisting of multiple stems may have to be collected. Some of this information may also be available from the literature. Table 4 summarises measurements which may be required/could be used to improve the current parameterisation of YieldSAFE.

Table 4. Possible measurements to improve current parameterisation of the YieldSAFE model.

Measurement	Method
Height Diameter at 10 cm and 50 cm (D_{10}, D_{50})	Physical measurement of trees first year regrowth and leaf area at field site in Forst.
Aboveground biomass	Height and diameter measurements (trees), above and below ground biomass for crop.
Maximum leaf area	Determination of total maximum leaf area, and moisture content of a sub-sample (tree and crop).
Soil moisture/available soil water	Soil moisture measurements will be used for modelling.

8 Acknowledgements

The AGFORWARD project (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD, Theme 2 - Biotechnologies, Agriculture & Food. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

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