# COMBINING SHORT ROTATION COPPICE WITH ANNUAL CROPS – MODERN AGROFORESTRY SYSTEMS FOR SUSTAINABLE LAND USE

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ABSTRACT: The production of fuelwood in short rotation coppice (SRC) is considered as one compartment in the upcoming intensification of the generation of renewable resources, which importance is undoubted in terms of reducing carbon dioxide in the atmosphere and gaining independence of fossil fuels. Increased production of biomass for energy recovery will intensify the pressure on land, leading to further intensification of agricultural management. Combining forestry and agricultural systems seem to be a promising solution. In a joint research project four agroforestry systems combining SRC strips and crop strips were established in Germany. Each site offers different initial conditions for combined wood and crop production. Main focus on all sites is the evaluation of economic and ecological issues. The objective is to deduce possibilities of improvement and to make relevant information available for practice and consultancy. Besides economic calculations, further research fields include microclimate, flora, fauna and soil properties. First results show significant impact on microclimate and biodiversity. Enhancing effects on crop yields seem to be associated with specific site conditions and do not occur necessarily. Without an economic consideration of ecosystem services today SRC agroforestry systems can not compete with single crop systems, but may become economically relevant with further progress of climate change.
Keywords: short rotation forestry (SRF), agriculture, agroforestry, sustainability, biodiversity, climate change

## 1 INTRODUCTION

The concept of silvoarable agroforestry became obsolete in practical land use in Europe some hundred years ago. In times of industrialisation of agricultural practice, the ancient methods of combining trees and annual crops on one site seemed redundant. To increase agricultural area and yield, landscape components such as hedgerows, copses and other boundary structures were removed. Side effects were an impairment of microclimatic conditions and landscape biodiversity as well as the enhancement of soil erosion and nitrate leaching. The theory of climate change reinforces the discussion about ecosystem services and the need for sustainable land use systems. With modern design, agroforestry systems may provide an opportunity in combining sustainability and productivity in agriculture with positive effects for environment and farmers.

Previous research on the topic of modern agroforestry stated possible advantages and characteristics coming along with this special form of agriculture [1]:

- Biomass productivity and profitability can be higher in agroforestry than in forestry or agricultural monocultures
- Agroforestry can be more sustainable than forestry or agricultural monocultures
- Behaviour of combined system components (trees, crops, animals) can not be predicted from their single use

The use of fast growing trees in order to produce woody biomass is considered as one component in the German strategy to increase the share of renewable energy in overall energy supply until 2020 [2]. So far, the cultivation of fast growing trees on German agricultural area is implemented only hesitantly by German farmers. In 2010 nationwide about 4000 hectare of plants for solid fuel (mainly energy wood and miscanthus) existed [3].

The joint research project "AgroForstEnergie „AgroForstEnergie – economic and ecological evaluation of agroforestry systems in farming practice", funded by the German Federal Ministry of Food, Agriculture and Consumer Protection" aims to combine both topics. It was initialised to look at alley-cropping systems which combine the production of woody biomass for thermal utilisation (short rotation coppice, SRC) with conventional field crops [4]. Superordinate targets are:

- Conserving productivity of the whole agricultural area,
- Production of highly demanded woody bioenergy sources on agricultural area,
- Diversification of agricultural production,
- Increase of yield stability of crops between SRC strips by windbreak effects,
- Implementation of structural elements in open landscapes to reduce erosion and increase the biodiversity in the agrarian landscape.

A total of four sites in Germany (located in Thuringia, Brandenburg and Lower Saxony) were chosen to evaluate economic and ecological issues. The objective is to deduce possibilities of improvement and to make relevant information available for practice and consultancy. Besides economic evaluation, further research fields include microclimate, flora, fauna and soil properties.

This paper aims in giving a glimpse into the actual work of evaluating agroforestry systems with short rotation coppice strips in Germany. First results will show tendencies of development as final statements can only be made after observation of a significant part of the agroforestry system life span.

## 2 EXPERIMENTAL DESIGN

### 2.1 Large scale cropland, Thuringia State, Germany

A 50 hectare field in a structurally poor and intensively agriculturally used area of Thuringia was chosen to establish a large-scale alley cropping system with short rotation coppice strips. Climatic site characteristics are an average yearly precipitation of 595 l m$^2$ and an annual average temperature mean of 8,8 °C. Soil texture is characterised by high amounts of silt and clay, soil type is Luvisol developed from shell limestone, ground water is not plant available.

Planting took place in spring 2007. High yield poplar clones „Max 1, 3, 4" were planted as cuttings in two different planting schemes (10.000 trees ha$^{-1}$ and 3.300 trees ha$^{-1}$). Harvest will take place after 4 years by a fully automatic mowing cutter and after 8 years by a feller buncher respectively. SRC strips are arranged South-North against the prevailing wind direction (West).

Three different distances (48, 96, 144 meter) between SRC strips are tested. Additionally several native forest species (*Populus tremula*, *Betula pendula*, *Fraxinus excelsior*, *Carpinus betulus*, *Robinia pseudoacacia* and a collection of flowering shrubs) were interspersed between the Max clones (Fig. 1) to increase ecological significance. Costs and benefits of all test parameter are analysed. Between the SRC strips a conventional crop rotation consisting of winter wheat, spring barely and winter rape is cultivated.

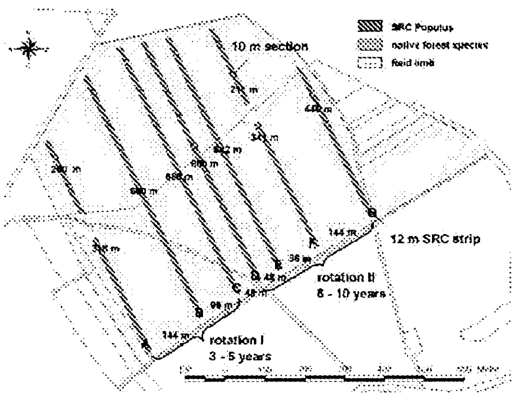


**Figure 1**: Experimental design of the large-scale agroforestry system in Thuringia

### 2.2 Recultivation area, Brandenburg State, Germany

The post-mining landscape in the Lusatian lignite-mining district, located in the Southern Brandenburg State (approx. 150 km south from Berlin, Germany) is characterized by low precipitation and marginal soils.

Due to these conditions crop yield is low, and hence, conventional land use systems often fail in terms of a reliable and efficient crop production. The production of short rotation woody biomass in alley cropping systems for bioenergy may be a promising alternative to improve soil fertility and to enhance the economical value of these post-mining areas. A central question at this site is whether the simultaneous cultivation of trees and crops at sites susceptible to drought stress will lead to an improved water availability and thus to increasing crop yields. In order to assess the overall impact of hedgerows on crop yields at poor sandy soils an alley cropping system was established in 2007. It is composed of 24 meter wide alleys (cultivated with alfalfa – *Medicago sativa*) and 11 meter wide tree hedgerows (consisting of four double rows of black locust – *Robinia pseudoacacia*; 9,200 trees ha$^{-1}$). The interactions between trees and crops will be characterized by measuring weather and yield data in different distances from hedgerows. Based on these results recommendations for an optimization of the tree-crop interaction will be developed in order to increase the reliability of plant production as compared to monocropping systems.

### 2.3 Cropland and pasture, Lower Saxony State, Germany

Especially on productive agricultural sites habitat structures were often removed in the course of intensification measurements by soil melioration. This led to a significant deterioration of the floral and faunal biodiversity. Therefore, particular emphasis was placed in the design of the alley cropping system established on cropland and pasture in Lower Saxony in spring 2008 in order to maximize structural diversity. Thus, the experimental design contains various poplar and willow clones that will be harvested in a 5-year rotation (poplar: Max, Hybrid 275, Koreana, Willow: Tora, Inger, Tordis).

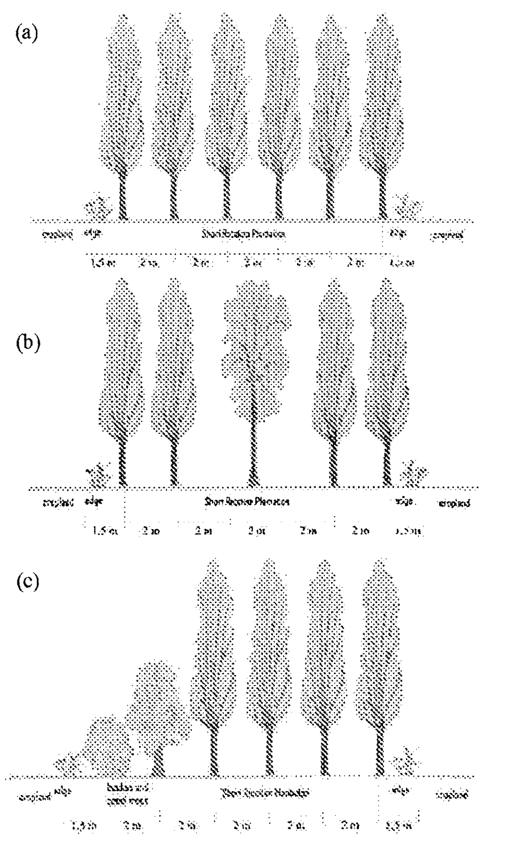


**Figure 2:** Experimental design of the agroforestry systems in Lower Saxony with uniform tree species (a), with inclusion of aspen trees (b) and with inclusion of shrubs and small trees (c)

Besides the conventional approach of planting (Fig. 2a) two more variations were adapted. The inclusion of aspen trees to be harvested in a 10-year rotation (Fig. 2b) provides additional opportunities for industrial use. The inclusion of autochtone shrubs and trees with staggered bloom times increases the ecological diversification along with positive effects on both the nectar and pollen supply for insects and the establishment of breeding bird species (Fig. 2c).

## 3 IMPACT OF SRC STRIPS ON CROP RELEVANT CLIMATE PARAMETER

### 3.1 Material and methods

Collection of data was realised by installation of meteorological stations measuring wind speed, precipitation and soil moisture (TDR) in three depth respectively, amongst others. Five meteorological stations were installed on the Thuringian large scale cropland site, with one reference station in unaffected distance from SRC strips and four stations in 8, 16, 45 and 75 meter distance lee side (sheltered from the wind) from SRC strip A respectively. Four meteorological stations were installed on the Brandenburg recultivation site, with one unaffected reference station and three stations in lee side, windward side and middle of the crop strip (12 meter distance to SRC strips) respectively.

Additionally, soil moisture was detected by gravimetric analysis on the Thuringian large scale cropland site at selected dates. Sampling sites were located in 0, 1, 2, 4, 8, 16 and 32 meter distance from SRC strip B in windward and lee side respectively.

### 3.2 Results and discussion

Considerable effects on crop relevant microclimatic parameter by SRC strips were detected. On the Thuringian large scale cropland site a wind speed reduction of 0,5 m $s^{-1}$ on average in the near lee side range of 8 meter occurred. The wind speed reducing effect was detectable also in 16 meter lee side. No effect could be measured in 45 and 75 meter distance from the SRC strip respectively (Fig. 3).

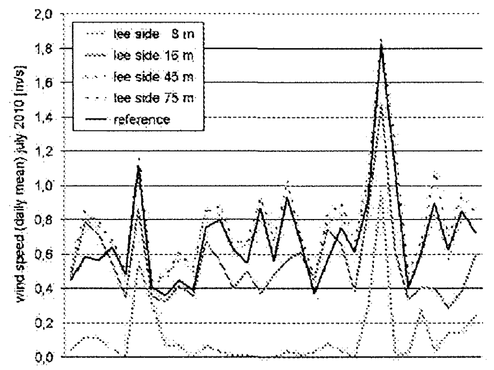


**Figure 3:** Daily wind speed means in 150 centimeter height in July 2010 on Thuringian large scale cropland as a function of distance from SRC strip

The measured effects in 2010 at the Thuringian site represent the impact of three year old high density (10.000 plants per hectare) poplar SRC strips. Average tree heights were 460 centimeter, average diameter at breast height 3,8 centimeter.

Investigations at the Brandenburg recultivation site also showed a quantifiable effect on wind speed by black locust SRC strips. In contrast to the Thuringian measurements, data collection was realised in 100 centimeter height according to lower crop heights.

Average wind speed reductions are 0,9 m $s^{-1}$ (50 % of reference) in the near lee side of SRC strips and 0,7 m $s^{-1}$ (62 % of reference) in the middle of the crop strip (12 meter) in 2010. Average tree heights of black locust in 2010 (three years after planting) were 330 centimeter, average diameter at breast height 3,4 centimeter.

Particularly relevant with regard to the importance of water availability for annual crop yield is the impact of SRC strips on soil moisture. Two processes are expected to affect soil moisture in the areas influenced by SRC strips. (1) The reduction of wind speed leads to a reduction of evaporation and therefore is considered to increase the moisture content of the topsoil. (2) The development of an effective root systems by fast growing trees will affect adjacent area of the SRC strips. Through tillage, roots are mechanically forced to concentrate on deeper soil horizons in the adjacent crop area. This should lead to a reduced soil moisture in the subsoil near SRC strips.

Data of the growing season 2009 from the Thuringian site show minimal differences in soil moisture in 20 and 40 centimeter depth which may originate from differing small scale soil properties (Fig. 4). In 60 centimeter depth lee side a gradual reduction of moisture content during the growing season occurred compared to the reference data . This seems to be attributed to the above discussed root effect. No proof could be found for the assumption of higher topsoil moisture content through reduction of evaporation.

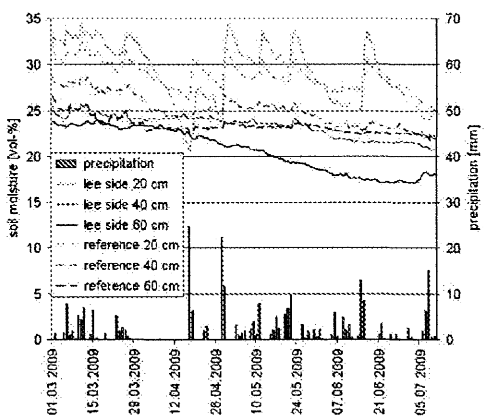


**Figure 4:** Soil moisture in three depth (20, 40, 60 centimeter) at unaffected reference station and in 8 meter distance from the SRC strip lee side during the growing season 2009

Data collected on the Brandenburg recultivation site confirmed the Thuringian findings. Only slight differences in soil moisture content occurred in 2010 between reference and alley cropping area. Detectable was a reduction of soil moisture content in 50 centimeter depth in May and June compared to the reference. The effect was demonstrated at lee side, windward side and in the middle of the crop strip respectively.

The additional measurements of soil moisture content as a function of distance from SRC strip showed only minimal effects at most sampling dates. Effects were more distinctive at dry periods with low soil water content levels. Figure 5 shows results from sampling date

08.06.2010 when soil moisture content level was relatively high (about 19 percent) compared with results from sampling date 12.07.2010 during summer drought when overall soil moisture was very low (about 12 percent) in the topsoil. Soil moisture increased linear in a transect from far windward side to lee side. Increase was highest at soil surface ($R^2_{0\text{-}10\,cm}$: 0,8306) and also detectable in deeper horizons ($R^2_{10\text{-}20\,cm}$: 0,3454, $R^2_{20\text{-}30\,cm}$: 0,489). In this case, plantation of SRC strips led to a better availability of soil water in plant relevant topsoil layers. Especially in periods with increased requirements by intensive plant growth positive synergetic effects result from the combination of tree strips and annual crops. The effect apparently results from the wind speed reducing effect of the tree strips, which is known to occur even at the near windward side of the windbreak [5].

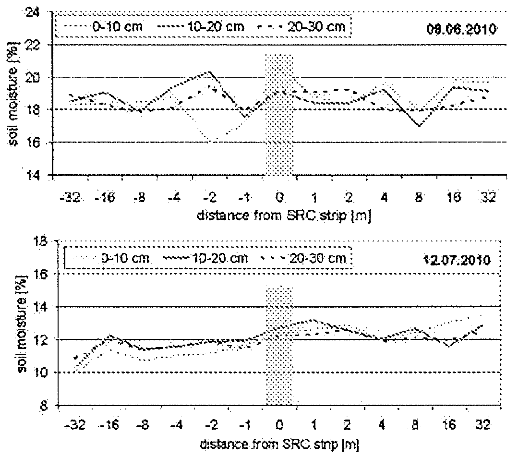


**Figure 5:** Soil moisture content in three depth (0-10, 10-20, 20-30 centimeter) at 08.06.2010 (above) and 12.07.2010 (below) as a function of distance from SRC strip windward side (negative distances) and lee side (positive distances)

4 IMPACT OF SRC STRIPS ON BIODIVERSITY

4.1 Material and methods

To detect biodiversity changes resulting from the integration of SRC strips in annual crop land several species groups are observed (Tab. I).

**Table I:** Observed species groups in the SRC agroforestry systems Thuringian large scale cropland (TH), Brandenburg recultivation site (BR) and Lower Saxony cropland site (LS)

| Species groups | TH | BR | LS |
|---|---|---|---|
| Higher plants | x | x | x |
| Birds | x | x | |
| Butterflies | x | | |
| Ground beetle | x | | |
| Spiders | | x | |
| Plant louse | | | x |
| Plant louse antagonists | | | x |

Observation of plants was realised by site inspection with registration of the entirety of occurring species and rating of respective dominance. Additionally plots with an area of 1 x 3 meter respectively were set following the location characteristics shown in Figure 6. The set of plots was repeated minimum four times at each site.

Evaluation of higher plants in plots took place following the Braun-Blanquet scale. Numbers of species and the proportion of the area covered by that species were detected.

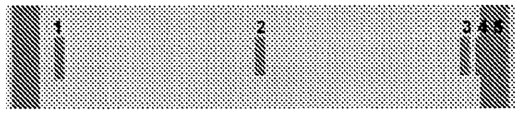


**Figure 6:** Location characteristics of biodiversity evaluation plots, 1: crop lee side, 2: crop middle, 3: crop windward side, 4: SRC strip edge, 5: SRC strip middle

4.2 Results and discussion

The observation of plant species at the Thuringian agroforestry system proves the diversifying effect of implemented SRC strips. Only minor species numbers have been counted in the crop area. In the SRC strip area species number was clearly higher (Fig. 7).

These findings were verified by results from the Lower Saxony cropland site (Fig. 8). Floristic species diversity of short rotation coppice strips is significantly higher compared to crop strip diversity.

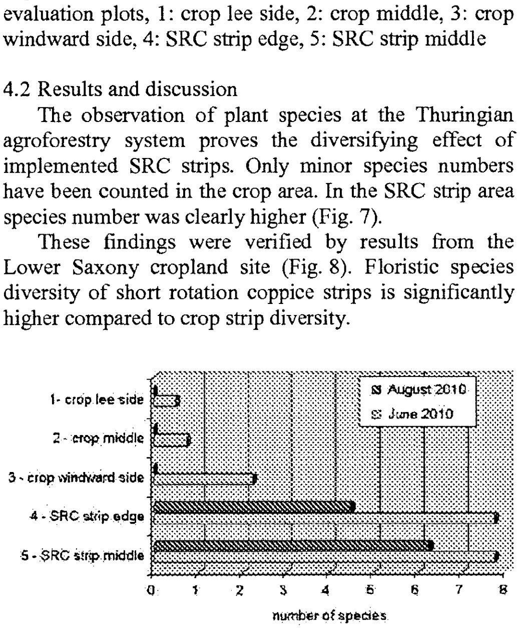


**Figure 7:** Average numbers of plant species in plots of 3 m² at different locations of the Thuringian agroforestry system in August and June 2010

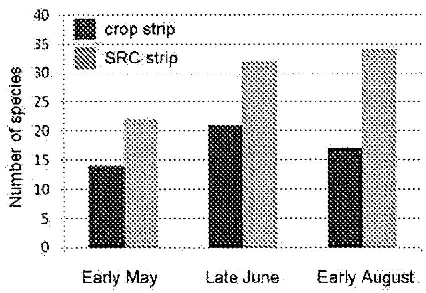


**Figure 8:** Floristic species diversity of crop strips and SRC strips

The pronounced differences of plant species numbers are clearly related to different management practises applied to annual crops and perennial trees respectively.

The moderate expenditure for plant protection as well as the long resting of the soil in short rotation plantations gives ideal conditions for dispersal of non-target-species. During the observed timespan of four years since planting of trees mainly species related to intensive crop management were detected. In the following years a shift in dominance from annual to perennial species in understorey vegetation is expected. Discovering to what degree species related to more tree dominant habitats will gain ground and how this evolution will affect species diversity of the complete system is the exciting task for the following years.

## 5 IMPACT OF SRC STRIPS ON ANNUAL CROP YIELD

### 5.1 Material and methods

Crop yield was measured directly on the combines by GPS connected flow meters since 2007 at the Thuringian as well as on the Lower Saxony cropland agroforestry sites. Data was analysed using a GIS. Moisture contents were normalised to 15 percent for wheat and to 9 percent for rape respectively, outlier data was identified and eliminated. Data was interpolated by kriging and geostatistically tested for significant dependency of crop yield on distance from SRC strips.

### 5.2 Results and discussion

As is shown in figure 9, crop yield varies strongly within the field. Besides variations which can be attributed to deviations of basic conditions such as slope angle, soil properties and nutrient supply, a distinct edge effect is visually detectable. The geostatistical evaluation verified significant dependencies of distance from SRC strips on crop yield (Fig. 10). This dependency increased since the beginning of the observation in 2007 and is also found in Lower Saxony crop yield data. It remains to be seen how overall crop yield develops in response to the implementation of SRC strips. This requires long time observations and inclusion of more than one crop rotation cycle. An observation over the following years will bring evidence about possible yield increase.

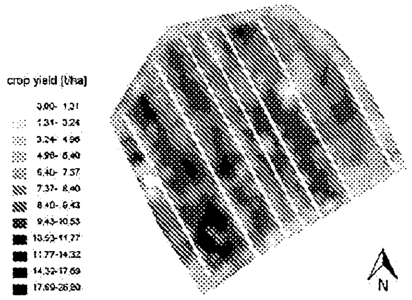


**Figure 9:** Spatial distribution of crop yield (winter wheat 2010) at the Thuringian agroforestry system

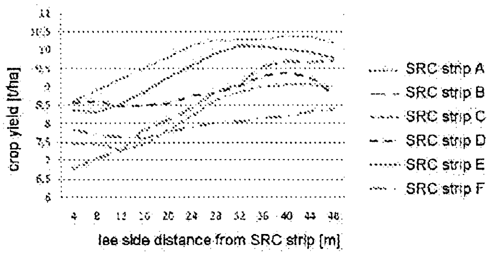


**Figure 10:** Dependency of distance from SRC strips on crop yield (winter wheat 2010) at the Thuringian agroforestry system

## 6 ECONOMIC EVALUATION OF SRC-AGROFORESTRY SYSTEMS

The competitiveness of agroforestry systems compared to monocultural cropping systems is mainly defined by the competitiveness of the single crop systems – in this case conventional cropping and short rotation coppice – and by their respective percentage of area in the system. Additionally, the shifting of labour expenditures as well as possible competitive and synergetic effects have influence. To analyse competitiveness of the single elements of an SRC agroforestry system several assumptions were made (Tab. II). Crop rotation is winter rape / winter wheat / silage maize / spring barley. Used data of working methods is based on the KTBL data pool [6]. To compare perennial with annual crops, annuities of ground rents for 20 years were calculated with an interest rate of 4 percent per year. The generated ground rents of SRC agroforestry systems are 7,9 percent lower than ground rents of pure cropping. The reason lies in the increase of labour expenditures with increasing field edges, which are artificially established be implementing SRC strips. Even with an adaption of crop strip width on machine working width leftover strips will result during some work steps which lead to a poor utilisation of agricultural machines.

The higher the percentage of SRC strips, the more difference between ground rents of agroforestry systems and ground rents of single crop systems is generated due to increasing labour expenditures. An additional positive or negative impact on crop yield in agroforestry systems can be generated by synergetic or competitive effects between SRC strips and annual crops. A reduced cooling between SRC strips during the night, an improved water availability between the SRC strips resulting from reduced evaporation and shelter of annual crops from wind caused damage may result in positive yield effects.

Competitive effects concerning light, water and nutrient may occur especially in the edge area of SRC strips. Also possible is an increased pest and weed infestation which may result in negative yield effects.

**Table II:** Exemplary calculation of profitability

| | | |
|---|---|---|
| Field area | 40 ha | |
| Farm-field distance | 5 km | |
| SRC strips | | |
| Number | 4 | |
| Width | 12 m | |
| Length | 862,5 m | |
| Percentage area | 10,4 % (4,14 ha) | |
| Strip distance | 96,7 m | |
| Planting density | 10.000 plants $ha^{-1}$ | |
| Planting costs | 0,15 € $cutting^{-1}$ | |
| Cultivation life time | 20 years | |
| Recultivation costs | 1300 € $ha^{-1}$ | |
| Crop yields and market prices | | |
| Winter rape | 3,5 t $ha^{-1}$ | 313,50 € $t^{-1}$ |
| Winter wheat | 8,0 t $ha^{-1}$ | 139,40 € $t^{-1}$ |
| Silage maize | 50 t $ha^{-1}$ | 30 € $t^{-1}$ |
| Spring barley | 6,0 t $ha^{-1}$ | 162,60 € $t^{-1}$ |
| SRC poplar | 10 t dm $ha^{-1}$ $a^{-1}$ | 81,75 € $t^{-1}$ |
| Ground rents | | |
| Single crop rotation 40 ha | | 104,96 € $ha^{-1}$ |
| SRC agroforestry system | | 96,69 € $ha^{-1}$ |

To be economically competitive with single crop systems, synergetic effects have to dominate in SRC agroforestry systems. Until now no yield improving effects of significant degree were detected. However, the latter are necessary to equal profitability of single crop systems. The development of synergetic effects is likely with increasing age of the studied agroforestry systems.

The further observation promises interesting results.

## 7 CONCLUSIONS

Modern agroforestry systems with fast growing trees may become a component in the provision of woody biomass for energetic use. They provide an opportunity to broaden farmers product range and therewith help to compensate fluctuations in agricultural markets.

Especially the impact of short rotation coppice strips on microclimatic parameters is supposed to contribute to more yield stability of arable crops. Particularly areas with reduced water availability due to high evaporation levels can benefit from the wind speed reducing effect of the tree strips. In terms of climate change, which is supposed to be attended by extreme weather events, SRC agroforestry systems may have a balancing effect. The establishment of short rotation coppice strips will deliver positive environmental effects by implementation of structural elements in open landscapes and a resulting improvement of habitat connectivity as well as an reduction of erosion risk. Nevertheless it may be hard to implement agroforestry systems in practical farming without offering additional incentive.

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