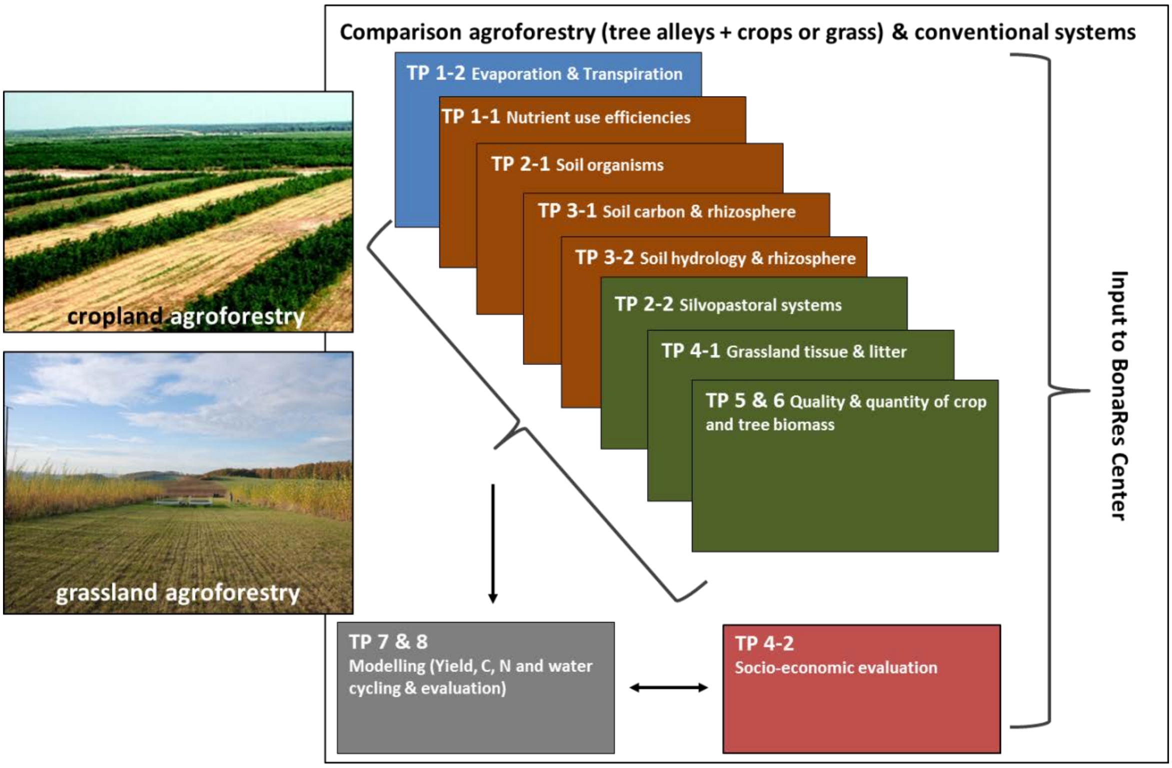
BonaRes-SIGNAL



Sustainable intensification of agriculture through agroforestry

Inhalt

1. General Description of the Joint and Integrated Project

1.1 Central objective

Central aim of our project is to evaluate whether and under which site conditions agroforestry in Germany can be a land use alternative that is ecologically, economically and socially more sustainable than conventional agriculture.

Central hypothesis: On marginal sites and sites with high potentials for leaching losses or soil erosion, **innovative agroforestry systems are ecologically and economically more sustainable and socially more acceptable** than conventional arable farming systems and, thus, improve the societal sustainability of modern agriculture.

Relation to the proposal call 'Soil as a Sustainable Resource for the Bioeconomy – BonaRes'

The BonaRes-SIGNAL collaborative proposal refers to the funding objectives of the tender 'Soil as a sustainable Resource for the Bioeconomy – BonaRes' in multiple ways:

- Within the BonaRes-SIGNAL consortium, we plan to evaluate **innovative agroforestry systems** (arable land or grassland with strips of fast growing tree species) which are land use systems with a high potential to **contribute to the sustainable supply of food, feedstuff as well as raw materials** for the Bioeconomy.
- We choose an **integrated approach** by studying **different environmental compartments** which are regarded as critical for the studied land use systems.
- In BonaRes-SIGNAL we will study how **soil functions can be optimized for agricultural production**, while at the same time **reducing the negative impacts on the environment** (e.g. nitrate leaching, erosion, CO_2 emissions).
- In this **interdisciplinary project**, we will investigate how **management** in agroforestry systems improves the habitat for **soil biocoenosis**, leading to more **optimal soil functions** compared to conventional agricultural practices.
- Our project will link **information on the functional diversity of the soil community with their activities, processes** (e.g. decomposition, gross N mineralization, gross N nitrification) and microbial residues, which has rarely been done before.
- The **sustainability of the agroforestry and conventional systems will be evaluated through the efficiency of nutrient cycling and water use**.
- Our project will be adapting and applying existing **computer models** that will include **simulation of functions and interactions of soil ecosystems** with the help of new and existing data on **agroforestry field experiments.**
- We will study the **profitability and social acceptance of agroforestry systems** in different regions of Germany. Agroforestry may help to improve the image of an agricultural enterprise or region and may thus contribute to an **improved societal sustainability of modern agriculture**.

Scientific objectives and hypotheses

1) To achieve an optimal input of root and leaf litter of crops, grass and trees so that the composition of the soil community, its functions (litter decomposition, N & P mineralization, N, P, K, Ca, Mg retention), and related soil properties (water holding capacity, aggregate stability) promote the efficient use of the nutrients N, P, K, Ca, Mg and water.

   Hypothesis: Compared to conventional agriculture, agroforestry systems improve soil biological functions, like litter decomposition, N & P mineralization, N, P, K, Ca, Mg retention and related soil properties (water holding capacity, aggregate stability), which in turn will improve their nutrient response efficiencies and water use efficiency.

2) To improve management (by choice of crop and trees, above- and belowground pruning, distance to tree rows) directed at the efficient functioning of roots and rhizosphere, including: the stimulation of microbial activities, optimal acquisition of water and nutrients and increased C input into the soil.

   Hypothesis: Roots and rhizosphere of agroforestry systems can be managed (e.g. by choice of crop and trees, above- and belowground pruning, distance to tree rows) to stimulate the complementary use of resources (water, nutrients) by trees and crops. This includes stimulation of root exudates that can alter the soil properties in a way that is optimal for the acquisition of water.

3) To model the complex interactions between the soil biological community, rhizosphere, nutrient cycling, water use and plant productivity in agroforestry and conventional agricultural systems (including competition for and complementarity of resources), for the evaluation of the ecological sustainability of both systems.

   Hypothesis: Successful evaluation of the sustainability of complex systems like agroforestry and conventional agriculture crucially depends on modelling tools that include competition for soil nutrients and water and use of complementary nutrient and water resources.

4) To conduct an economic analysis on the implementation of agroforestry systems at the farm level and to conduct an empirical acceptance analysis and societal valuation of agroforestry systems.

   Hypothesis: In regions with marginal soil and climatic conditions and in areas with soils endangered by soil erosion and nitrate leaching, innovative agroforestry systems are economically sustainable and socially more acceptable than conventional arable farming systems and, thus, improve the social/societal sustainability of modern agriculture. Higher social acceptance of agroforestry systems can be observed in all types of regions, i.e. in regions with marginal as well as high productivity conditions.

1.2 Scientific background and current status of research (general part for whole project)

Sustainable intensification of agriculture and agroforestry

Agricultural production has increased remarkably over the past four decades, reaching historically high values, and is currently able to feed a global population of more than 7 billion people (Tilman et al. 2002). However, the agricultural practices that have been so successful in increasing global food supply have also resulted in unintended, negative impacts on the environment and on ecosystem services, emphasizing the need for more sustainable agricultural methods. Since a few decades people are aware of the need to increase the global agricultural production with better environmental protection ('sustainable intensification of agriculture') as shown by several review articles (Matson et al. 1997, Cassman 1999, Tilman et al. 2002). However, at present intensification of agriculture is still mainly attained through high fertilizer, water and pesticides use and new crop strains, and does not try to take advantage of ecological interactions within agricultural systems, which are crucial to secure high-productivity agriculture in the future (Robertson and Swinton 2005).

In natural ecosystems, the activity of a highly diverse community of soil microorganisms and invertebrates regulates key ecosystem properties such as decomposition, soil nutrient cycling and soil structure that directly affect productivity, without negative impacts on the environment. In agricultural systems, the composition and activity of the soil community differ markedly from natural ecosystems (Roesch et al. 2007) which may severely reduce the biological regulation of decomposition and nutrient availability in soils. In intensive agriculture this decoupling from biological activity is substituted by the use of mineral fertilizers and mechanized tillage. However, the addition of relatively mobile mineral nutrients which are not well synchronized with crop demand, and the inability of the soil biological community to retain excess nutrients, have led to leaching losses to surface or groundwater and trace gases emission to the atmosphere (Matson et al. 1997).

Sustainable intensification of agriculture can be attained if land use systems are designed that combine modern ecological knowledge of the functioning of ecosystems with traditional knowledge on farming. This awareness has stimulated renewed interest in agroforestry since there are several reasons why agroforestry systems are better able to mimic the functioning of natural ecosystems than monoculture crops. In general, growing trees with crops will be beneficial when the trees are able to acquire resources (water, light or nutrients) that the crop would otherwise not acquire, but will not be beneficial if the trees and crops are competing for the same resources (Cannell et al. 1996, Devkota et al. 2009). Agroforestry systems can have higher water use efficiency than annual crops since trees in agroforestry systems can utilize deep water outside the rooting zone of annual crops and outside the crop growing season. However, whether agroforestry systems can influence overall water consumption by reducing wind speed and affect infiltration rates at the field scale is still debated (Herbst et al. 2007). Furthermore, studies have shown that agroforestry systems can make more efficient use of available nutrients since deep tree roots can provide a 'safety net' against nutrient leaching (Lehmann et al. 1998), supply nutrients from deep layers that are normally considered beyond the reach of crops (Dechert et al. 2005), and take up nutrients at times when crop demand is low. Other improved benefits that are often ascribed to the incorporation of trees in agro-ecosystems include stabilized or increased soil organic matter levels (Oelbermann et al. 2004), improved aggregates stability, and stimulated extracellular enzyme activities (Udawatta et al. 2008). Agroforestry systems in developed countries have only very rarely been analyzed in agricultural economics. Due to a growing interest in this land use system, some preliminary economic analyses have been conducted (Musshoff 2012). In Europe it has been shown that growing trees and crops in agroforestry systems generated a higher value of ecosystem services than growing them separately (Graves et al. 2007), see also Fig.1. Also in Germany, inclusion of tree components in agro-ecosystems is an approach that deserves thorough evaluation since there are no obvious reasons why agroforestry systems would not be equally successful, especially on 'marginal sites' and sites with high risk of nitrate leaching or erosion. Furthermore, agroforestry systems as an environmentally friendly land use have potential in marketing strategies which can enhance the image of an agricultural enterprise or a region (Reeg 2011).

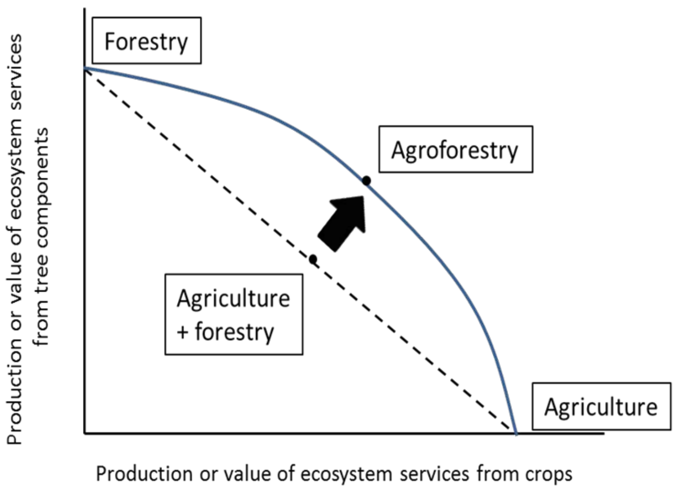


Fig. 1. A major hypothesis of agroforestry is that the integration of tree components with agriculture can lead to a higher productivity and higher value of ecosystem services per area than separated agricultural and woodland systems (Graves et al., 2007)

Nutrient response efficiencies- four steps for higher productivity

Traditional dose-response curves for fertilizer-yield relations (Cerrato and Blackmer 1990) often ignore that nutrient response efficiencies have various components as illustrated in Fig. 2 (Noordwijk 1999). **Quadrant 1** at the lower left of Fig. 2 shows the relation between inputs of nutrients to the soil (e.g. in the form of crop residues, fertilizers) and the nutrients available in the soil during the growing season. This relation, the *application efficiency,* depends on inherent soil fertility, residue quality and quantity, timing, priming effects, placement, soil microbial processes (e.g. N-immobilization) and leaching. **Quadrant 2** shows the relation between available nutrients and nutrient uptake by crops. The main drivers of this *uptake efficiency* are water uptake by roots, microbial biomass turnover, and enzyme activities. **Quadrant 3** shows the relation between nutrient uptake and biomass production. This *utilization or use efficiency* depends on factors such as weather conditions, cultivars,

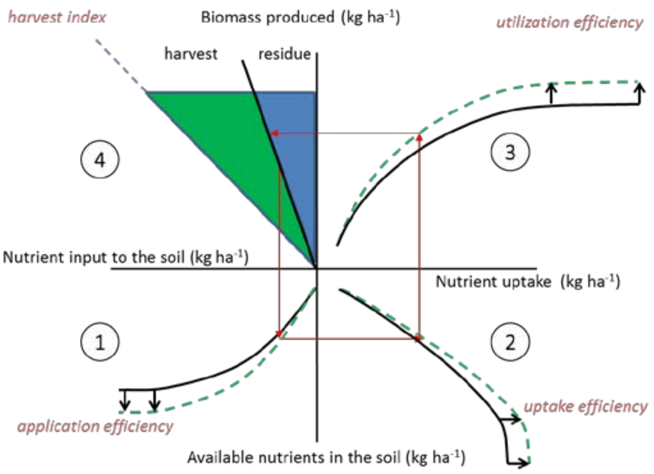


Fig. 2. Conceptual four-quadrant diagram (van Noordwijk, 1999) illustrating the various components of nutrient response efficiency at plot level. For explanation see text. Green dashed curves show the hypothetical changes of an agroforestry system compared to a monoculture cropping system (solid black curves).

pests and competition. Finally, **Quadrant 4** displays the *'harvest index'*, the ratio of harvest to biomass produced. Using these ideas, it was shown that in temperate grasslands nitrogen (N) response efficiencies depended on management and were mainly driven by N uptake efficiency rather than N use efficiencies (Keuter et al. 2013). Furthermore, it was shown at the same sites that microbial N immobilization rather than plant N uptake reduced N losses (Hoeft et al. 2014). It has frequently been observed that management practices, influencing the quantity and quality of plant residues, also influence the activity and diversity of soil organisms (Fliessbach et al. 2007). However, only very few studies exist for soils under agroforestry (Lagomarsino et al. 2011) and none was conducted in Germany. Labelling of plant residues in combination with analysis of microbial residues will give insights into the processes controlling nutrient application, uptake and utilization efficiencies and is thus essential to link soil biological functions to the efficient use of nutrients. Earthworms, a key component of soil fauna that affect nutrient cycling through their feeding and burrowing activities, are also strongly influenced by management (Metzke et al. 2007). How their abundance and diversity links to nutrient dynamics in agroforestry systems is presently unknown. Whether agroforestry systems in Germany are indeed more efficient in nutrient cycling than conventional systems is also currently unknown. Since trees in agroforestry systems have the potential to acquire nutrients that crops would otherwise not acquire, this would potentially increase the ecosystem's application efficiency and uptake efficiency making the four-quadrant diagram a useful concept to evaluate agroforestry systems (Fig. 2).

Water use efficiencies

Water use efficiency (WUE) expresses the biomass or grain yield produced per unit of water used by the land use system (Hatfield et al. 2001). Water use of crops and woodlands in the same region can vary significantly, particularly with respect to partitioning of evapotranspiration into transpiration, soil evaporation and interception evaporation (Hörmann et al. 2008). Water uptake by roots is governed by water availability, root biomass and the spatial distribution of roots, but also by rhizosphere processes. In particular, mucilage exudation may play a key role in attenuating drought stress by keeping the rhizosphere wet and helping roots to take up water from drying soils (Carminati and Vetterlein 2013). For agroforestry systems it has been suggested that deep roots of trees can bring additional water to the top soil via hydraulic lift, providing a safety reservoir of water for shallow-rooted crops (Caldwell and Richards 1989). When evaluating the water balance of agricultural systems, several components (run-off, soil evaporation and drainage) do not contribute to crop productivity. Although there is evidence that agroforestry has the potential to increase WUE by reducing these unproductive components (Ong et al. 2002), it is presently unclear and scientifically very challenging to evaluate whether agroforestry systems in Germany have higher water use efficiencies than conventional agriculture.

1.3 Detailed description of work plan of the project

Research approach

In our research alliance we plan to compare existing experimental agroforestry systems in Germany with adjacent conventional agricultural systems. The agroforestry systems that we will evaluate were established between 2007 and 2011 (Table 1) and a lot of site-specific information has been collected since establishment, however, the individual agroforestry experiments have been used to answer different questions using a wide variety of methods. In Bonares-SIGNAL we plan a coordinated approach, in which we will conduct a systematic comparison of these unique experimental sites using a uniform methodology. Apart from productivity, profitability and social/societal acceptance we will evaluate these land use systems for nitrogen (N), phosphorus (P), potassium (K), Calcium (Ca) and Magnesium (Mg) response efficiencies and water use efficiencies and their link to rhizosphere and soil biological processes. Since interactions between the soil biological community, rhizosphere, nutrient cycling, water use and plant productivity are complex they can only be evaluated when measurements are combined using a modeling approach. Our endeavour is only possible with inputs from different disciplines and we have organized the BonaRes-SIGNAL research alliance accordingly. Our research sites include five existing long-term alley cropping agroforestry experiments (arable crops with strips of fast growing trees) in Germany covering a gradient of soil and climatic conditions. Furthermore, we include two grassland sites, both consisting of grassland with strips of fast growing trees. See for details Table 1.

Core design

All sites (Table 1) have in common that they consist of strips of fast growing trees either with arable crops or grassland. Strips of fast growing trees create variability in the performance of trees and of cropland and grassland. It has been shown in earlier studies that close to the transition from trees to crops/grassland competition for resources is highest while further away crops/grassland may benefit from the presences of the tree strips. This is why the distance from the tree strips plays a central role in our core design. The distance between strips varies, but most agroforestry-cropland sites include a treatment of 48m between tree strips (with the exception of Reiffenhausen where the distance between the strips is 12m). In the agroforestry-grassland sites the distance between tree strips is 48m for Mariensee while in Reiffenhausen the distance between tree strips is 9m. Within BonaRes-SIGNAL we have agreed on a common design (Fig. 3). This design consists of **4 replicate plots**; in case of agroforestry-cropland 30m long, with width varying from 24m to 12m (Reiffenhausen only); in case of agroforestry-grassland 24m long, with width varying from 24m (Mariensee) to 4.5m (Reiffenhausen) and **4 control plots** (10m x 10m) in the neighbouring control site (having the same crop/grass and management as the agroforestry treatment, but without strips of trees). Using these core plots, we will be able to investigate the effects of tree strips on soil processes and biomass production by sampling at multiple distances from the transition of trees to arable crops/grassland to the middle of the strips with arable crops/grasslands. In all agroforestry-cropland sites we will select poplar (clone mix "Max") as fast growing trees, while in the agroforestry-grassland sites we will select willow (different genotypes). Replicate plots will be allocated using a stratified random procedure. We are aware that we will not be able to investigate all possible factors using our common design in the first three years; however, based on the results from the first phase we plan to adjust the common design in the second phase to study additional factors.

Central services

We plan to conduct detailed soil hydrological and meteorological measurements at each site on one replicate plot both in agroforest and in the control. Soil water sensors will be installed as part of the central services by TP1 following the design that we agreed upon (Fig. 3, at some sites soil depth is less than a meter and the depth at which sensors will be installed will be adapted accordingly). In this design we will measure soil water content at different distances to the tree strips, which will yield information on how tree strips affect soil water content (e.g. through uptake by roots or changes in wind speed).

As part of the central services we will also conduct a soil sampling during establishment of the core plots at all sites. Soil samples for analysis of soil chemical and soil physical properties will be taken at each replicate plot; at fixed distances from the transition of tree strips to arable crops/grassland in the agroforestry plots and from fixed sampling points in the controls. Locations for soil sampling in the agroforestry sites will be: one sample in the tree strips and samples at the following distances from the tree strips: 1, 3, 7 and 24m (or the middle of the strip of arable crops / grassland strips). At each replicate plot and each distance to the tree – crop/grassland transition we will take 8 subsamples which will be pooled in a composite sample for analysis. Soil samples will be taken at pre-defined depth intervals (0-0.30m, 0.30-0.60m). Soil samples for bulk density measurements will be sampled from the soil pits that will be temporally established during installation of the soil moisture sensors.

All subprojects that will sample for soil biological properties and for biomass estimates will also follow a similar design at fixed distances from the transition of the tree strips to arable crops/grassland.

Plans for the second and third phase

Based on the results of the first phase (3 years: 01.06.2015 – 31.05.2018) we intend to continue with BonaRes-SIGNAL in a second and third funding phase (up to six years). In the second phase we intend (1) to add other variables to our core design that are not covered during the first phase due to resource limitations; (2) to use the improved and calibrated models to make knowledge-based prognosis of functional processes in soils and locations other than our present sites and to extrapolate results to larger areas and communicate this to stakeholders; and (3) to contribute our knowledge to the development of the web-based portal for sustainable soil management decisions.

1) Variables that will affect/improve the efficient management of water and nutrients and improve soil fertility included in the design of the 2nd phase are e.g.: other tree species (e.g. Robinia pseudoacacia); additional distances between the strips of fast growing trees and treatments with reduced fertilizer application (to test whether the higher nutrient use efficiencies in agroforestry systems can be used to come to a better fertilizer management).

2) To test how well the improved and calibrated models can be used to make a knowledge based prognosis of functional processes in soils at other locations, we intend to include some other alley cropping agroforestry experiments in the 2nd phase of BonaRes-SIGNAL. One option is an experiment established in Göttingen in 2012 that is presently not old enough but may be an ideal location to validate modelling results from the first phase. Other experiments that may be added are experimental sites in Bavaria and Baden-Württemberg. Extrapolation of results will not only focus on the soil processes and production of the land use systems but also include interactions between ecological, economic and social systems.

3) With our calibrated models we will support the development of a web-based portal for sustainable soil management decisions that will be developed by the BonaRes-Centre.

The third phase will focus mainly on extrapolation using our modelling tools and to improve the related web-based portal for sustainable soil management decisions. Experimentally, we envision a test focussing on the long-term rotation of strips fast growing tree species to evaluate whether fast growing tree strips can reduce compaction of the subsoil due to heavy machines, which is presently one of the major unsolved problems in modern agriculture.

Depending on our results from the first phase and the financial possibilities, we may consider to add or change one or two groups in our consortium during the second and third phase. This may be because the requirements of expertise in the 2nd and 3rd phase will change compared to the first phase and because we may add or change a group that is managing an agroforestry experiment that is presently not part of the BonaRes-SIGNAL consortium.

Table 1: Basic information on sites, soils and age of experiments

	Site	Long-term annual precipitation (vegetation period)	Crop / rotation	Tree component	Soil type (texture)	Productivity index (Ackerzahl)	Start / age
Cropland agroforestry	Dornburg	584 (308) mm	winter rape / winter wheat / summer barley	Rows of poplar as short rotation coppice	Luvisol (Clayey silt)	up to 50	2007
	Forst, Lausitz	556 (300) mm	corn / potato / winter wheat	Rows of Black locust, poplar, oak, maple, ash as short rotation coppice	Gleyic Cambisol (Loamy sand/sandy loam)	45	2010
	Wendhausen	555 (294) mm	Winter rape / winter wheat / winter barely corn / field bean	Rows of poplar as short rotation coppice	Vertic Luvisol / Cambisol (loamy clay)	46	2008
	Reiffenhausen	642 (312) mm	Summer wheat / winter barley / winter rape / winter wheat	Rows of poplar as short rotation coppice	Cambisol (sandy loamy)	35-57	2011
Grassland agroforestry	Reiffenhausen	642 (312) mm	Grassland strips ("grass-clover mixture" and "biodiversity mixture, 32 species")	Rows of willow plantations as short rotation coppice	Cambisol (sandy loamy)	35-57	2011
	Mariensee	620 (294) mm	Grassland strips	Rows of willow plantations as short rotation coppice	Histosol (peat on sand)	~20	2008

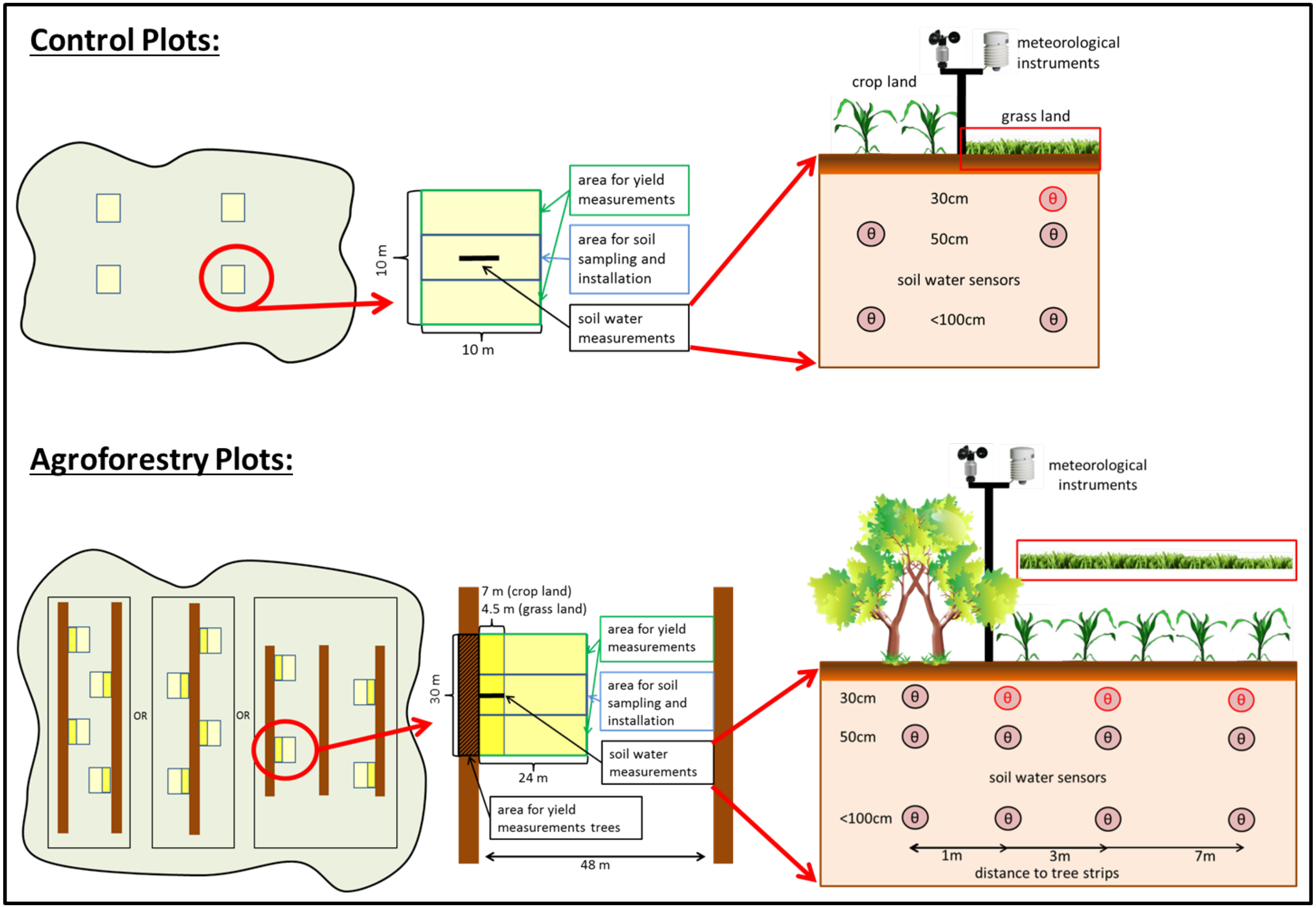


Fig. 3: BonaRes-SIGNAL experimental design, consisting of 4 replicate plots in the agroforestry sites and 4 control plots in the neighbouring control site (having the same crop/grass and management as the agroforestry treatment, but without strips of trees). Furthermore the planned installation of soil water sensors is depicted.

1.4 Verwertungsplan (Gesamtvorhaben)

In den tropischen Regionen, aber durchaus auch in den gemäßigten Breiten Europas, bilden Agroforstsysteme (AF) eine historisch tief verankerte und z.T. bis heute wichtige und erfolgreiche Form der Landnutzung ("Tropical Gardens", Dehesas / Montados auf der iberischen Halbinsel, Streuobstwiesen in Zentraleuropa). Auch in Nordamerika und Kanada hat man über die letzten Jahrzehnte zunehmend den ökologischen und ökonomischen Mehrwert dieser Form der Landnutzung (wieder-)entdeckt, so dass hier sowohl bezüglich der Forschung aber insbesondere auch im Hinblick auf die Umsetzung erhebliche Aktivitäten zu verzeichnen sind (siehe dazu u.a. www.aftaweb.org; www.centerforagroforestry.org).

Angeregt durch die laufenden Aktivitäten in Nordamerika aber auch durch intensive Vorarbeiten vor allem in Frankreich (www1.montpellier.inra.fr/safe), Großbritannien (http://www.agroforestry.co.uk) und Deutschland (agroforst.uni-freiburg.de) hat das Thema AF auch für diese Regionen in den letzten Jahren zunehmend an Aufmerksamkeit gewonnen. Insbesondere um den agrarpolitischen Rahmenbedingungen der EU gerecht zu werden, haben sich in Folge sowohl eine europäische (EURAF; www.agroforestry.eu) als auch zahlreiche nationale agroforstliche Vereinigungen gebildet (für Deutschland www.gpw.uni-kiel.de/de/arbeitsgemeinschaften). Dennoch spielt eine moderne agroforstliche Landnutzung flächenmäßig in der deutschen Landwirtschaft bisher keine wesentliche Rolle. Es existieren lediglich historische Anwendungen wie z.B. Knicks in Norddeutschland als so genannte "Windbreaks" oder die besonders in Baden-Württemberg noch intakten oder auch andernorts aufgegebenen (z.B. Thüringen) Streuobstwiesen.

Wissenschaftliche Erfolgsaussichten

Die Ursachen für die bisher geringe Wahrnehmung und Anwendung moderner agroforstlicher Ansätze in Deutschland liegen im Wesentlichen in i) einer besonders durch die Intensivierung der landwirtschaftlichen Bewirtschaftung aber auch historisch gewachsenen scharfen Trennung von Land- und Forstwirtschaft (Zunahme an Großschlägen, "kein störender Baum auf meinem Acker"), ii) einer Wissenslücke über mögliche Vorteilswirkung von Bäumen auf landwirtschaftlichen Flächen und iii) einer fehlenden Förderkulisse für AF und damit einer vorherrschenden Unsicherheit bezüglich der Rentabilität derartiger Systeme.

Mittels der Ergebnisse von SIGNAL sollen auf den angesprochenen Ebenen deutliche Verbesserungen erreicht werden. Dabei liegt der Schwerpunkt unserer geplanten Aktivitäten auf dem so genannten "Alley Cropping", also der Kombination von Acker- bzw. Graslandwirtschaft mit Streifen von Gehölzen in Form von Kurzumtriebsplantagen (KUP). Hier besteht durch die offensichtliche Möglichkeit zur Verbindung von ökologischen und ökonomischen Vorteilswirkungen (z.B. Ertragserhöhung durch Windschutz + Energieholzerzeugung) derzeit das attraktivste Angebot zur Umsetzung agroforstlicher Anwendungen in der deutschen Landwirtschaft. Zur Projektdurchführung hat sich ein in der Materie bereits langjährig erfahrendes Konsortium zusammengefunden, das zum Teil in Vorläuferprojekten direkt und erfolgreich kooperiert hat (z.B. www.best-forschung.de; www.agroforstenergie.de) und das die wesentlichen fachlichen Fragestellung zur Thematik abdeckt (Funktionale Bodenbiologie, Rhizosphärenforschung, Nährstoffkreisläufe, Biomassedynamik, Wasserhaushalt, Modellierung sowie Sozioökonomie). Zudem soll neben der ackerbaulichen Komponente ein besonderes Augenmerk auf Grünlandflächen gerichtet werden. Auch hier ergeben sich ausgesprochen interessante Möglichkeiten für den Einsatz eines "Alley Cropping" mit KUP als Option zur Nutzung überschüssigen Grünlands. Insgesamt besitzen alle beteiligten Personen und Institutionen einschlägige und renommierte Erfahrungen zur Thematik und werden somit zur sicheren Durchführung und Umsetzung des beantragten Vorhabens beitragen.

Der geplante Schwerpunkt der ersten Projektphase liegt in der koordinierten Datenerhebung auf der Basis von Felduntersuchungen. Primäres Ziel der zweiten Projektphase ist die Entwicklung und Überprüfung von Entscheider-Unterstützungsprogrammen für die praktische Anwendung. Dazu sollen die in der ersten Phase generierten Daten aus den Freilandversuchen dem Modul B (BonaRes-Centre) zugeführt und in enger Rückkopplung zwischen den Expertisen aus Modul B und den einzelnen TPs für die Umsetzung ausgewertet und aufgearbeitet werden. Beide Arbeitsschwerpunkte sollen begleitet werden durch eine ständige Information der fachlichen Praxis sowie aller sonstigen "Stakeholder" (Beratungsinstitutionen, Verwaltungen, Politik, Öffentlichkeit). Dies soll über die üblichen Medien und Veröffentlichungskanäle geschehen (Homepage, Flyer, landwirtschaftliche Fachpresse, Pressegespräche und –konferenzen, Feldbegehungen etc.). Dabei wird insbesondere der Demonstration von entsprechenden agroforstlichen Anwendungen mittels der beteiligten Versuchsfelder ein besonderer Stellenwert zugemessen. Zudem ist durch die direkte Beteiligung von praxisnahen Forschungseinrichtungen (Thüringer Landesanstalt für Landwirtschaft (TLL); Julius Kühn-Institut (JKI) Braunschweig) gewährleistet, dass auch eine institutionelle Kontinuität hinsichtlich der Verbreitung und Umsetzung des generierten Wissens gegeben ist.

Wirtschaftliche Erfolgsaussichten

Die Wirtschaftlichkeit der deutschen und auch der übrigen Landwirtschaft in der EU ist primär geprägt durch die Subventionspolitik. So wurden bisher insgesamt pro Jahr ca. 55 Milliarden EUR - und damit mehr als die Hälfte des gesamten EU-Haushaltes - zur Förderung der Landwirtschaft aufgebracht, wobei Deutschland ca. sechs Milliarden EUR pro Jahr an Förderung erhalten hat. Im Mittel stammen damit ca. 44 % des Einkommens in der deutschen Landwirtschaft aus Brüssel. Förderschwerpunkt sind die Direktzahlungen über die so genannte "erste Säule" der EU Förderpolitik. Dabei erhielten ca. 0,5 % der deutschen Landwirtschaftsbetriebe mehr als 300.000 Euro pro Jahr an Flächen- und Betriebsprämien aus Brüssel, was ca. 20 % der gesamten Direktzahlungen entspricht. Die Mehrzahl der vor allem kleinen und mittelständischen Betriebe erhält weniger als 10.000 Euro pro Jahr. Trotz einer Reduktion und Verschiebung der Direktzahlungen in Richtung der zweiten Fördersäule durch die 2013 durchgeführte Reform der Gemeinsamen Europäischen Agrarpolitik (GAP 2014-2020), ist eine grundsätzliche Änderung dieser Verteilung nicht absehbar.

Damit ist die Beurteilung von wirtschaftlichen Erfolgsaussichten eines praxisnahen landwirtschaftlichen Forschungsvorhabens, wie das beantragte Projekt SIGNAL, grundsätzlich geprägt durch mögliche Rückwirkungen hinsichtlich der EU Förderpolitik. Dies gilt im besonderen Maße für die kleineren

Betriebe, da diese durch den anhaltenden Strukturwandel im ländlichen Raum und die geringen Möglichkeiten zur Erhöhung der Subventionsquote oftmals bereits am Existenzminium agieren.

Mit Blick auf die jüngst durchgeführte GAP-Reform und die darin enthaltenen Änderungen hinsichtlich des "Greenings" sowie die Umschichtung in Richtung zweiter Fördersäule (Förderung der Entwicklung des ländlichen Raumes) ergeben sich jedoch insbesondere auch für mittlere und kleine Betriebe neue Chancen. Dabei wurde in beiden Fördersäulen das Thema "Agroforst" als Optionen für ökologische Vorrangflächen berücksichtigt (EU Verordnung 1307/2013 zur Direktzahlung) bzw. gegenüber der vorherigen Periode mit Blick auf die tatsächliche Nutzbarmachung signifikant erweitert (EU Verordnung 1305/2013 zur Förderung der ländlichen Entwicklung).

Somit wurden durch die EU entscheidende Rahmenbedingungen gesetzt bzw. verbessert, die eine positive mittel- bis langfristige Perspektive im Hinblick auf die geplanten Aktivitäten von SIGNAL ergeben: über die gezielte und systematische Zusammenführung von bereits in Deutschland vorhandenen Forschungsansätzen und –vorhaben zu Agroforst sollen die von der EU gesetzten Rahmenbedingungen mit wissenschaftlichen Daten und Erkenntnissen unterfüttert werden. Nur so erscheint es realistisch und aussichtsreich, dass langfristig auch die landwirtschaftliche Praxis an die Optionen und die Vorteilswirkungen einer agroforstlichen Landnutzung herangeführt bzw. davon überzeugt werden kann. Durch die bereits überarbeitete Rahmensetzung zu AF durch die EU wird somit prinzipiell eine hohe Erfolgsaussicht des Vorhabens mit Blick auf die landwirtschaftlichen Betriebe erwartet.

Entscheidend für die eher kurzfristige Einführung bzw. Umsetzung von AF ist allerdings das Verhalten der einzelnen Bundesländer. Sie sind zuständig für die genaue Ausprägung der tatsächlichen Förderung über die zweite Fördersäule. Obwohl das Verfahren für die anstehende Förderperiode noch nicht abgeschlossen ist, zeichnet sich jedoch schon jetzt ab, dass AF hier noch weitgehend unbekannt ist und damit wenig berücksichtigt wurde. Die eher kurzfristigen Erfolgsaussichten für das Vorhaben SIGNAL beziehen sich daher auf die positive Wirkung durch die Verbreitung des erzielten Wissens bzw. die Demonstration von Möglichkeiten über die Flächenarbeit. Zudem beinhaltet das Vorhaben als Referenz zu agroforstlichen Vorgehen die so genannte "konventionelle Praxis". Aus dem Vergleich sollen mögliche Vorzüge einer agroforstlichen Anwendung und damit, insbesondere mit Blick auf die ökologische Effizienz, die mögliche Überlegenheit des agroforstlichen Lösungsansatzes zu Konkurrenzlösungen herausgearbeitet werden.

Insgesamt ergibt sich über das Projekt SIGNAL eine wertvolle und dringend notwendige Möglichkeit zur Verzahnung von Wissenschaft und Praxis, die zur Durchführung der übergeordneten Ziele (EU-GAP-Reform) unabdingbar ist.

Nutzen für verschiedene Anwendergruppen

Landwirtschaftlich-ökologische Fragestellungen erfahren eine stetig zunehmende Aufmerksamkeit. Dies gilt insbesondere im Hinblick auf den Verlust an Diversität durch die unaufhaltsame Intensivierung der Landwirtschaft, als auch mit Blick auf die Nutzung begrenzter Ressourcen (u.a. Anbauflächen, Boden, Trinkwasser). In diesem Zusammenhang liefert die gewählte Thematik "Agroforst" insbesondere auch im Kontext der geänderten EU Agrarpolitik einen breitgestreuten Nutzen für verschiedene Anwendergruppen. Dabei sind die vier wichtigsten Zielgruppen für die Untersuchungsergebnisse:

i) die nationale und internationale wissenschaftliche Gemeinschaft als die übliche "Kontrollinstanz" sowie zum Austausch und Abgleich von neuen wissenschaftlichen Erkenntnissen,
ii) die nationale Landwirtschaft als direkter Akteur zur Umsetzung der gewonnenen Erkenntnisse in die Praxis,
iii) landwirtschaftliche Beratungsinstitutionen und entsprechende Akteure auf kommunaler und administrativer Ebene (z.B. Landvolk) sowie
iv) die interessierte Öffentlichkeit, einschließlich fachlich ausgerichteter NGOs (z.B. NABU).

Durch die interdisziplinäre Zusammensetzung des Konsortiums ist gewährleistet, dass alle Zielgruppen hinreichend mit entsprechenden Daten, Erkenntnissen und Handlungsvorschlägen versorgt werden. So werden neben den rein naturwissenschaftlichen Fragestellungen insbesondere auch die sozioökonomischen Aspekte über das TP4-2 explizit mit einbezogen. Über die von Beginn an stringente Planung und Koordination des Vorhabens (u.a. einheitliches Plotdesign für die Feldmessstationen, einheitliche Aufnahme- und Analyseverfahren, zeitlich abgestimmte Beprobungskampagnen) sowie die abgestimmte Modellierung zum Wasser- und Stoffhaushalt über das TP8 ist gewährleistet, dass die gewonnenen Daten im hohen Maße vergleichbar, übertragbar und zur Weiterverarbeitung im geplanten Modul B (BonaRes-Zentrum) genutzt werden können. Zudem sollen die Ergebnisse von SIGNAL direkt über die üblichen wissenschaftlichen Kanäle (Publikationen, Vorträge, Buchbeiträge etc.) aber auch über spezielle Ausarbeitungen und Aktionen für die Praxis verbreitet werden. Dazu zählen u.a. Pressemitteilungen, speziell ausgerichtete Feldbegehungen sowie Projekt-Workshops und –Symposien. Weiterhin besteht über Mitglieder des SIGNAL-Konsortiums ein direkter Zugang zu entsprechenden Fachverbänden (u.a. Deutsche Bodenkundliche Gesellschaft, DBG, Gesellschaft für Pflanzenbauwissenschaften, AG-Agroforst Deutschland), so dass eine Diskussion, Weitergabe und Nutzbarmachung neuer Erkenntnisse gesichert ist. Auch bestehen überlappende Mitgliedschaften und direkte Mitwirkungen z.B. auch in F&E Projektbegleitvorhaben (u.a. NABU / Agrarholz), so dass auch hier ein Transfer bzw. eine Nutzbarmachung für spezifische Interessens- und Fachgruppen (NGOs) gewährleistet ist.

Um neue Anbausysteme in die landwirtschaftliche Praxis zu überführen, bedarf es neben der üblichen wissenschaftlichen Überprüfung mittels entsprechender Feldversuche einer Reihe weiterer Maßnahmen, um insbesondere die Landwirte selbst aber auch deren Berater von der Sinnhaftigkeit entsprechender Maßnahmen zu überzeugen. Dazu zählt vor allem, dass die jeweils zuständigen Verwaltungsorgane (u.a. Landwirtschaftsbehörden der Länder, untere Naturschutzbehörden der Kreise und Kommunen, Akteure der Wasserwirtschaft) hinreichend und rechtzeitig über geplante Innovationen und Neuerungen informiert und aufgeklärt werden. Letztendlich sind es diese Einrichtungen und deren Akteure, die zusammen mit den Landwirten mittel- bis langfristig für die Umsetzung der Ergebnisse aus dem Forschungsvorhaben verantwortlich sind.

Hinsichtlich des Themas "Agroforst" besteht vor allem bei den entsprechenden Verwaltungsorganen ein großes Informationsdefizit. In der Regel besteht eine unwissende oder historisch negativ geprägte

Sichtweise bezüglich der Anwesenheit von Bäumen auf Ackerflächen. Oftmals ist nur die klassische "Streuobstwiese" als Agroforstsystem bekannt. Zudem werden reine KUP-Plantagen fälschlicherweise unter Agroforstsystemen subsummiert.

Das Ziel von SIGNAL ist es daher, mittels der beteiligten Expertisen entsprechende Informations- und Aufklärungsarbeit zu leisten. Dazu soll auch hier der Zugang über die Thematik "Agrarförderung" gesucht werden. Insbesondere im Zusammenhang mit der Thematik des so genannten "Greenings" und der Förderung des Ländlichen Raums (ELER) erscheint das Thema "Agroforst" bzw. KUP in Form eines agroforstlichen "Alley croppings" schon jetzt ausgesprochen interessant. Zu erwarten ist, dass es erst nach einer ausgeprägten Einführungs- und Demonstrationsphase von entsprechenden agroforstlichen Anwendungen zur tatsächlichen wirtschaftlichen Anschlussfähigkeit und Umsetzung kommt. Die Grundlage für die wissenschaftliche Anschlussfähigkeit des beantragten Vorhabens ist dadurch gegeben, dass es für entsprechende Zwischenevaluationen zu den Fördermaßnahmen (z.B. ELER) einer wissenschaftlichen Datengrundlage bedarf. Mittel- bis langfristig liefern die Ergebnisse von SIGNAL damit die Datengrundlage zur Evaluation der Umsetzung von EU-Fördermaßnahmen auf der Landesebene bzw. auf der Ebene der Akteure.

Da neben den ökologischen Aspekten letztendlich der Ertrag im Vergleich zur konventionellen Landwirtschaft im Vorhaben SIGNAL die entscheidende Maßeinheit zur Bewertung des Ansatzes "Agroforst" bildet, ergeben sich direkte Auswirkungen hinsichtlich der Wirtschaftlichkeit der beteiligten Betriebe. Es wird erwartet, dass sich landwirtschaftliche Betriebe mit agroforstlichen Ansätzen langfristig besser am Markt behaupten als solche ohne eine derartige Diversifizierung in der Landnutzung.

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Finanzübersicht Verbundforschungsvorhaben BonaRes-Signal

Antragsteller	**TP**	**Summe**
Prof. Dr. E. Veldkamp / Prof. Dr. N. Lamersdorf / Dr. M. Corre	*Teilprojekt: TP1 / 1*	346.251,00
Prof. Dr. A. Knohl / Dr. L. Siebicke	*Teilprojekt: TP1 / 2*	221.098,00
Prof. Dr. E. Veldkamp	*Teilprojekt: TP1 / 3*	122.000,00
	Summe TP 1	689.349,00
Prof. Dr. Ch. Wachendorf / PD Dr. M. Potthoff / Prof. Dr. R.G. Jörgensen	*Teilprojekt: TP2 / 1*	155.364,00
Prof. Dr. M. Wachendorf	*Teilprojekt: TP2 / 2*	191.414,00
	Summe TP 2	346.778,00
Prof. Dr. Y. Kuzyakov / Dr. M. Jansen	*Teilprojekt: TP3 / 1*	148.728,00
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	Summe TP 7	180.739,00
PD Dr. E. Priesack	*Teilprojekt: TP 8*	133.496,00
	Summe TP 8	133.496,00
	Gesamtsumme EUR:	**2.256.951,00**

2. Description of Subprojects

TP1-1 Nutrient response and nutrient retention efficiencies in agroforestry systems

Principal Investigators: E. Veldkamp[1], N. Lamersdorf [2], M.D. Corre[1]

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Scientific background and current status of research; previous work

Conventional agricultural systems are very productive and profitable but not efficient in using soil nutrients, which may cause serious environmental problems (Tilman et al. 2002). Agroforestry systems (i.e. combination of crops and trees) are innovative agricultural systems in that they take advantage of beneficial ecological functions of their components, which are crucial to attain high productivity with possibly less environmental effects (Robertson and Swinton 2005). Presently, there is a lack of understanding on beneficial interactions or possible competitions for resources (soil nutrient availability, water, light) in agroforestry systems. Growing trees with crops will be beneficial when trees are able to acquire resources that crops would otherwise not use, but will be detrimental to productivity if trees and crops are competing for the same resources (Cannell et al. 1996, Devkota et al. 2009). In a temperate grassland, used for hay production (Solling uplands, Germany) with different management practices, we have successfully used the index of nitrogen response efficiency (NRE, the amount of plant biomass produced per unit of plant-available nitrogen) as a tool to evaluate the efficiency with which soil nitrogen is used by plants (Keuter et al. 2013). In this study, fertilizer application decreased NRE through decreases in both nitrogen uptake efficiency (plant nutrient uptake per supply of available nutrients) and nitrogen use efficiency (NUE, biomass produced per plant nitrogen uptake) whereas mowing frequency and sward composition affected NRE through nitrogen uptake efficiency rather than NUE (Keuter et al. 2013); mowing thrice a year resulted in larger NRE than mowing once a year, and the control grass sward (with inherent species composition) had larger NRE than the dicot-enhanced grass sward. Also in a temperate deciduous forests (Hainich National Park, Thuringia, Germany), we found that nutrient response efficiency is an excellent tool to analyse facilitation (i.e. one species alters conditions or resource levels which favours other species) and competition among mono- and mix-species tree stands (Schmidt et al. 2015). We were able to quantify the effects of individual tree species on a species' productivity between mono- and mix-species stands: based on nutrient response efficiency curves (of N, P, K, Ca and Mg), beech trees in mix-species stands had optimal P and K response efficiencies whereas beech trees in mono-species stands showed P and K limitations; oak trees in both mono- and mixed-species stands had K response efficiency beyond the optimal level; and hornbeam and lime trees both in mono- and mixed-species stands are not limited by any of the soil nutrients we investigated (Schmidt et al. 2015). Furthermore, to evaluate the efficiency with which soil available nutrients are retained in an ecosystem (i.e. including retention in soil and not just in vegetation), nutrient retention efficiency (1 − nutrient losses/soil available nutrient) is a crucial tool that can be used as basis to minimize nutrient losses. In a temperate grassland, we used nitrogen retention efficiency to evaluate the environmental sustainability of different management practices (Hoeft et al. 2014). This index was shown to be more informative than just merely the measures of nitrogen losses because the relative importance of soil processes and vegetation uptake as nutrient retention mechanisms can be quantitatively evaluated. In the same study, we showed that microbial N immobilization contributed more to high nitrogen retention efficiency in the soil than plant uptake (Hoeft et al. 2014).

Our objectives are to 1) evaluate how efficiently nitrogen (N), phosphorus (P), calcium (Ca) magnesium (Mg) and potassium (K) are being used in agroforestry systems compared to conventional management, using indices of nutrient response efficiencies and nutrient retention efficiencies; 2) assess whether differences in nutrient retention efficiencies between agroforestry and conventional agricultural systems is related with differences in microbial nutrient-cycling processes in the soil or by differences in plant uptake of nutrients; and 3) investigate the existence of facilitation and/or competition in soil nutrient resources between trees and crops in agroforestry systems compared with conventional agricultural systems.

Preliminary work and previous achievements of the applicants

Prof. Dr. Edzo Veldkamp and Dr. Marife D. Corre are both at the Büsgen Institute - Soil Science of Tropical and Subtropical Ecosystems, Faculty of Forest Sciences and Forest Ecology, University of Göttingen. The researches of their group focus on the sustainability of land-use systems and the impact of global change processes (e.g. increased nutrient deposition, land-use changes, climatic changes) on soil carbon and nitrogen dynamics and vegetation productivity (Powers et al. 2011, Baldos et al. in press). The group has many years of experience in interdisciplinary research projects that deal with the sustainability of agroforestry systems (Corre et al. 2006, Veldkamp et al. 2008). Methods that they apply include: stable isotope tracing, isotope dilution methods, soil-atmosphere trace gas flux measurements, soil nutrient availability and leaching measurements, and soil water modelling. One of the approaches their group used to evaluate the sustainability of land-use systems is the efficiency with which nutrients are used both at the tree or crop level and at the stand or ecosystem scale (Hoeft et al. 2014).

Prof. Dr. N. Lamersdorf is deputy head of the Büsgen Institute - Soil Science of Temperate Ecosystems, Faculty of Forest Sciences and Forest Ecology, University of Göttingen. His section is involved in various national and international studies on nutrient and water cycling in forest ecosystems. Since 2006, N. Lamersdorf and his research group is additionally focusing their research activities on the production of woody biomass in plantation and agroforestry systems at the national (e.g., NOVALIS project, www.dbu.de/643publikation949.html; BEST project, www.best-forschung.de) and European level (the EU-ERANET project RATING-SRC, www.ratingsrc.eu). As a coordinator and a PI in the field of soil science and forest nutrition, his work is an interdisciplinary approach on the impact on plantation forestry and agroforestry systems on various environmental services. He is also a founding member and the national delegate of the 2011 formed EU Agroforestry Federation EURAF (http://euraf.isa.utl.pt) and PI of EURAF in the recently started EU project AGFORWARD (AGroFORestry that Will Advance Rural Development; http://www.agforward.eu/index.php/en/). Finally, he is representative of the German working group "Agroforst" in the German Crop Science Society (Gesellschaft für Pflanzenbauwissenschaften e.V.; http://www.gpw.uni-kiel.de/de/arbeitsgemeinschaften).

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Detailed description of the work plan

We will measure nutrient response efficiency and nutrient retention efficiency for N, P and macronutrient cations (Ca, Mg, K) at all sites and treatments. N, P, Ca, Mg and K response efficiencies will be calculated as the product of N, P, Ca, Mg and K uptake efficiency by plants and N, P, Ca, Mg, K use efficiency by plants. N, P, Ca, Mg and K retention efficiencies will be assessed both at the stand level (tree or crop) and ecosystem scale (considering both tree and crop). We plan to measure all parameters (see below) at all sites (6 sites, see Table 1) and replicate plots (4, see Fig. 3)) at 0, 1, 7 and 24m distance from the tree strips (4 distances), in total 6 x 4 x 4 = 96 locations. Similarly, all parameters will be measured at the control sites (6 sites x 4 replicates plots = 24 locations). Timing of the sampling will be coordinated with TP2-1 (Wachendorf & Joergensen) and TP3-1 (Kuzyakov & Jansen).

Nutrient response efficiency: (plant N, P, Ca, Mg, K concentrations x plant biomass ÷ plant-available N, P, Ca, Mg, K) x (plant biomass ÷ plant N, P, Ca, Mg, K concentrations x plant biomass)

Plant biomass and plant nutrient concentrations. Plant biomass (for tree strips, grass swards and crop yield) will be measured by the subprojects managing these sites (TP2-2; TP5; TP6 and TP7). They will also take plant samples (e.g. sunlit leaves of trees, and composite samples of grass, crop biomass and grain). Plant N, P, Ca, Mg, K concentrations will be analysed from composition samples taken from all sites, treatments and distances using standard methods (by pressure digestion in HNO_3 and analysed for element concentrations using inductively coupled plasma-atomic emission spectrometer, ICP-AES) in our laboratory: (http://www.uni-goettingen.de/en/analysis-of-soilwaterair-samples/ 84010.html).

Plant-available N will be measured by in-situ net N mineralization assay (using the buried bag method) and will be conducted three times during the growing season. At each location, two intact soil cores will be taken in the top soil (0.0–0.05-m depth). We will focus this measurement only on the topsoil, which have the largest microbial activity and impact of land use and management. The soil from one core will be extracted with 0.5 M K_2SO4 directly in the field (T_0 cores). The other soil core will be put in a plastic bag and incubated in-situ for ten days, and extracted in a similar manner (T_1 cores). Gravimetric moisture content will be determined from part of the soil in a core upon arrival in the laboratory in order to calculate the dry mass of K_2SO4-extracted soil in the field. Mineral N will be analysed using continuous flow injection colorimetry (see web site for methods in our laboratory as above). Net N mineralization will be calculated as the difference between T_1- and T_0-mineral N (NH_4^+ + NO_3^-). This assay of net production of mineral N in the soil under in-situ conditions provides an index of plant-available N since during the incubation plant uptake is the only process excluded for the fate of mineral N produced by the microbial processes of N mineralization and nitrification (Hart et al. 1994). From the three measurement periods during the growing season, the total amount of plant-available N from the soil during the growing period will be calculated by trapezoidal interpolation between net N mineralization rates and sampling period interval. For the NRE calculation, the amount of N fertilizer and N deposition from bulk precipitation will be added to the plant-available N from the soil to comprise as the total plant-available N.

Plant-available P will be measured using resin- and sodium bicarbonate-extractable P (P_{resin} and P_{NaHCO3}) in the top 5-cm depth. These two extractions are part of the widely-used Hedley fractionation and are assumed to represent the fraction of soil P that is available for plant uptake (Cross and Schlesinger, 1995). This measurement will be conducted three times during the growing season, at the same sampling period for the net N mineralization assay. Freshly sampled soils will be shaken in distilled water for 12 h together with 1 g of pellet-shaped anion exchange resin (DOWEX 41081 analytical grade, Serva Electrophoresis GmbH, Heidelberg, Germany) kept in a tea bag. Subsequently, the tea bags containing the exchange resins will be cleaned with distilled water and shaken in 0.5M HCl for 12 h. These will be centrifuged, and the supernatant will be analysed for P. For P_{NaHCO3}, the soil from which P_{resin} had been previously extracted will be filled with 30 ml of 0.5 mol L^{-1} $NaHCO_3$, shaken overnight and the extract will be filtered. P content in both fractions will be determined using inductively coupled plasma-atomic emission spectrometer (ICP-AES, iCAP 6300 Duo VIEW ICP Spectrometer; Thermo Fischer Scientific GmbH, Dreieich, Germany). Gravimetric moisture content of the fresh soil will be determined to calculate the dry mass of extracted soil. From the three measurement periods during the growing season, the average plant-available P will be used (since this measure is not of P transformation rate but of fraction of P, e.g. in unit of g P/ m^2) for the growing season. In the NRE calculation, the amount of P fertilizer will be added to the plant-available P as the total plant-available P.

Plant-available Ca, Mg and K will be determined as the exchangeable Ca, Mg and K in the soil, which is normally used as an index of these macronutrients availability for plant uptake. This will be determined once during the growing season since this fraction of exchangeable nutrients in the soil is not going to change within one growing season. Soil samples will be taken at 2 depths: 0-30 cm (plowlayer depth) and 30-60 cm, in order to have a more detailed soil characteristics analysis than just merely at the top depth. Soil samples will be air-dried, sieved through 2-mm sieve, and percolated with unbuffered 1 mol L^{-1} NH_4Cl. Concentrations of Ca, Mg and K in the percolates will be determined using the ICP-AES (see above). These soils will also be analysed for standard soil characterization: total C, total N, effective cation exchange capacity, base saturation and pH, using established analytical methods in our laboratory (see above).

Nutrient retention efficiency: 1 – (N, P, Ca, Mg and K leaching losses from the soil) ÷ (N, P, Ca, Mg and K availability in the soil)

Nutrient losses by leaching will be estimated by measuring the N, P, Ca, Mg and K concentrations in soil water below the rooting zone (e.g. at 1.5-m depth). We will sample soil water approximately biweekly to monthly for a year using suction cup lysimeters in all sites, treatments and distances. The element concentrations representing a sampling period will be multiplied with the soil water drainage flux during a certain period (bi-weekly or monthly), simulated from the soil water submodel of the Expert-N model (TP 8). This is similar to the method we employed in our earlier study (Hoeft et al. 2014). The annual leaching losses are then the sum of biweekly or monthly leaching losses during a year of measurement. Analytical methods for N (total N by ultraviolet-persulfate digestion followed by hydrazine sulfate reduction (Autoanalyzer Method G-157-96), NH_4^+ by salicylate and dicloro isocyanuric acid reaction (Autoanalyzer Method G-102-93), and NO_3^- by cadmium reduction method with NH4Cl buffer (Autoanalyzer Method G-254-02) using continuous flow injection colorimetry (SEAL Analytical AA3, SEAL Analytical GmbH, Norderstedt, Germany) and for P, Ca, Mg and K concentrations in soil water (ICP-AES) are well established in our laboratory (see above).

N availability in the soil will be used, instead of plant-available N, because this includes not only the fraction that is available for plant uptake but also the fraction recycled by microbial processes. This is measured using the gross rate of soil-N cycling using ^{15}N pool dilution technique (Davidson et al. 1991). We will measure gross soil-N cycling rate in the topsoil (0-0.05-m depth), the depth that has the largest microbial activity and impact of land use and management e.g. (Corre et al. 2003, Corre and Lamersdorf 2004). Our group has extensive experience of this technique in many studies in temperate forests and grasslands and tropical agroforestry systems (Corre et al. 2003, Corre et al. 2007, Corre et al. 2010). We will carry out these measurements in situ, as we found that laboratory incubations did not reflect actual soil N-cycling rates in the field (Arnold et al. 2008). Since this method is labour intensive and expensive, we plan to conduct these measurements only once during the growing season, but in all locations (sites, replicates and distance) of the core design. These measures of gross soil-N cycling rates can also be linked with the soil chemical and physical characteristics and with the functional profiling of soil microbial community by TP2-1 in order to understand the mechanisms underlying the changes in N retention efficiencies between agroforestry and conventional agricultural systems. Using the same ^{15}N pool dilution techniques on the same soil cores, we can also calculate rates of NH_4^+ and NO_3^- immobilization and dissimilatory NO_3^- reduction to NH_4^+, which are the most important processes of N retention in the soil. P, Ca, Mg and K annual leaching losses from drainage water will be ratioed to the soil available P, and exchangeable Ca, Mg and K, described above.

Verwertungsplan

Die spezifische Verwertung von TP1-1 zielt auf die Optimierung der Nährstoffaufnahme und Nährstoffrückhaltung durch agroforstliche Anwendungen - und damit letztendlich auf die Steigerung von landwirtschaftlichen Ertragsleistungen durch eine verbesserte Ausnutzung der vorhandenen Nährstoffvorräte. Die Arbeiten konzentrieren sich auf die Hauptnährelemente N, P, K, Ca und Mg und auf Handlungsanweisungen in Richtung Düngung und Bewirtschaftung von Ernterückständen und Streueinträgen. Dabei sind bezüglich N u.a. auch spezifische Ergebnisse und Verwertungs-möglichkeiten mit Blick auf den Gewässer- und Klimaschutz zu erwarten (Reduktion der Nitrat- und N_2O-Austräge). Bezüglich P und K ergeben sich spezielle Auswirkungen hinsichtlich einer verbesserten Ökonomie (Reduktion von Düngekosten) sowie langfristige Möglichkeiten zur Aufwertung von Bodenqualitäten durch die Förderung oder Regenerierung von bodenbiologischen Prozessen (Residualverwertung, Streuumsatz). Durch den Einsatz standardisierter Mess- und Auswertungserfahren für Standorte mit unterschiedlichen Randbedingungen kann davon ausgegangen werden, dass die in TP1-1 erzielten Ergebnisse im hohen Maß zur Übertragbarkeit taugen werden. Gleichzeitig liefern die Daten aus TP1-1 einen wichtigen Baustein für die Modellierungen in TP7 (Yield-Safe) und TP8 (Expert-N) sowie die Auswertungs- und Umsetzungsansätze im BonaRes Zentrum.

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TP1-1 (Veldkamp, Lamersdorf & Corre)	**Nutrient response & efficiency; central services and coordination**											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student, postdoc, student assistance for field installations) **(M)**												
Purchase of equipment for soil chemical (e.g. lysimeter for soil solution sampling) and soil physical (e.g. TDR; data logger, GPRS) field stations **(M)**												
Installation and first test runs of soil chemical and soil physical field stations **(M)**												
Soil chemical and soil physical field stations completed and ready to work, start of continuous parameter registration and data transfer **(D)**												
Processing and first evaluation of incoming field data **(M)** and data transfer to modelling TP (7, 8) and to data base of BonaRes-Centre **(D)**												
Annual project meeting **(M)** and annual / final reports **(D)**												
Fieldwork on measurements of soil-available nutrients **(M)**												
Data on soil- and plant-available nutrients ready analysed and transferred to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Results of nutrient analysis communicated to stakeholders, supply of guidelines for practical management **(D)**												
Manuscripts on (1) nutrient retention efficiency and (2) response efficiency written and submitted **(D)**												

TP1-2 The influence of agroforestry on evaporation and transpiration

Principal Investigators: Alexander Knohl[1], Lukas Siebicke[1]

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Scientific background and current status of research; previous work

Both nutrient uptake efficiency and nutrient utilization efficiency in agro-ecosystems depend on the water status of the vegetation. Plant water status is not only influenced by precipitation and soil water content but also by evapotranspiration rates which are controlled by meteorological conditions (including solar radiation, wind and atmospheric turbulence), physiological responses of the plants and land management activities (Jones 1992).

The sum of evaporation and transpiration represents the turbulent flux of water vapour between soil, vegetation and atmosphere (Shuttleworth and Wallace 1985). Turbulent flux measurements by the eddy covariance technique (Aubinet 2000) have evolved as the method of choice for ecosystem scale atmospheric flux assessments (Baldocchi 2008). Numerous studies have investigated evaporation and transpiration from a variety of forests as well as from various conventional agricultural crops and grasslands, providing a solid foundation for the measurement and interpretation of water vapour fluxes from extensive monocultures (e.g. Williams et al. 2012). However, little is known about water fluxes from multiple species systems, particularly structurally complex arrangements of trees and low vegetation, as is the case in agroforestry systems (Ward et al. 2012). Not only are water fluxes specific to the individual components, e.g. owing to different water use strategies and rooting depths of trees and annual crops, but trees also modify the wind field and atmospheric turbulence (Ward et al. 2012). This in turn can modify atmospheric controls of evapotranspiration rates (transfer resistances) from agroforestry systems relative to conventional mono-specific agricultural crops. Finally, there is a lack of understanding of how trees and agricultural crops interact when grown in mixture adjacent to each other, and how far this interaction reaches out from contact zones. Specifically it remains unclear how this interaction alters fluxes from the total system and how the tree and crop components might compete or complement each other in terms of their use of light and water resources.

Scientific understanding of water and nutrient cycles in the soil-plant-atmosphere system requires multidisciplinary research, which links soil, plant, and atmosphere components through complementary measurements and coupled modelling. Thus the atmospheric component of TP1-2 (Knohl, Siebicke) will address specifically all above aspects of water fluxes from vegetation to atmosphere, providing atmospheric boundary conditions for the research of other TPs on soils and crops.

Transforming fundamental understanding of tree and crop components in agroforestry systems into deliverables for their implementation in practice further requires expressing system responses as a function of management parameters. It is therefore necessary not only to compare agroforestry to conventional agriculture but also to apply a uniform research strategy across a number of sites along gradients of site properties (climate, soils) as well as management parameters of agroforestry systems (width, spacing and orientation of tree elements in the mixture, rotation age). This involves integrating site-specific measurements from a standardized sampling design into modelling frameworks (spatially resolved water fluxes), which allow altering management parameters (crop parameters, e.g. spatial arrangement of trees), therefore providing the basis for advice to the practitioner through tools like the BonaRes-Centre.

The overall objectives of the atmospheric component of TP1-2 are to investigate how different agroforestry systems affect evaporation and transpiration. The total water use will be assessed in a way complementary to the “land equivalent ratio” used by TP7, and the competition between trees and crops in agroforestry systems, which is also highlighted in the description of TP3-2, will be studied here with respect to water use. The specific objectives are:

a) Assess evaporation and transpiration rates of different agroforestry systems (mixed system including strips of fast growing trees) at ecosystem level and quantify how they differ relative to the reference, namely conventional agriculture (monoculture without trees),

b) Assess evaporation and transpiration rates specifically for tree and agricultural crop components,

c) Quantify by measurements and modelling relevant meteorological drivers of water fluxes at high temporal and spatial resolution as the basis for the interpretation of water fluxes from the different vegetation components,

d) Assess the interaction (competition, facilitation) of trees and agricultural crops in the combined agroforestry system in terms of water and light resources and provide those findings as boundary conditions to the work of other TPs on distributions of nutrients (TP1-1) and productivity (TP2-2, TP5, TP7) of agroforestry systems (see work plan below for detailed links to other TPs in the consortium).

Preliminary work and previous achievements of the applicants

The Chair of Bioclimatology at the Büsgen-Institute, Faculty of Forest Sciences and Forest Ecology focuses - in research and teaching - on the interaction between ecosystems and the atmosphere. We aim to understand biogeochemical and water cycles as well as the ecophysiology of terrestrial ecosystems. We investigate how those systems are impacted by land use management and how they respond to anthropogenic as well as naturally induced changes of the environment. The group operates research sites (eddy covariance flux towers and meteorological stations) in Germany (Solling, Hainich, Leinefelde, Göttinger Wald) and Indonesia (Sulawesi and Sumatra).

Prof. Dr. Alexander Knohl works on biosphere-atmosphere interaction with a particular focus on measuring and modelling the exchange and transport of energy, water and trace gases at the atmosphere-plant-soil interface. Recent publications include the effect of land management on surface temperature (Luyssaert et al. 2014) and radiation, carbon and water flux modelling in differently managed forests ecosystems (Knohl et al. 2008). In his research, he employs a wide variety of ecological and micrometeorological techniques such as eddy covariance, leaf gas exchange, soil respiration, and stable isotopes of carbon and oxygen in combination with process-based land surface and atmospheric modelling. Recent projects include the BMBF-funded project "Bioenergie-Regionen stärken" (BEST), where his subproject investigated the effect of bioenergy plantations on biosphere-atmosphere interactions (Tölle et al. 2013).

Dr. Lukas Siebicke is an expert in the field of micrometeorology with a particular focus on turbulent energy and matter fluxes assessments through measurements and modelling. His research investigates how vegetation of natural ecosystems interacts with the atmosphere through exchange of water vapour, carbon dioxide, methane and energy and how those interactions are modified by management of production systems. Dr. Siebicke has years of expertise with trace gas fluxes in forested system. He has previously conducted research on coupled tree-grassland systems, turbulent water and carbon fluxes of Short Rotation Forestry (SRF) bioenergy systems, the impact of management activities on the carbon sequestration capacity of productive forestry and he has deployed large scale turbulent flux towers in agricultural systems. Complementary to his solid background in managing ecosystem scale field measurements he applies and develops micrometeorological models for trace gas flux partitioning, flux footprint modelling as well as high resolution 3D wind modelling.

The project is carried out in collaboration with Dr. Mathias Herbst (now at Thünen-Institut für Agrarklimaschutz, Braunschweig), who is coordinating the German part of the European Integrated Carbon Observation System (ICOS) and who is expert on ecophysiology of agricultural and forested landscapes.

5 most relevant publications:

Luyssaert S, Jammet M, Stoy PC, Estel S, Pongratz J, Ceschia E, Churkina G, Don A, Erb KH, Ferlicoq M, Gielen B, Grünwald T, Houghton RA, Klumpp K, Knohl A, Kolb T, Kuemmerle T, Laurila T, Lohila A, Loustau D, McGrath MJ, Meyfroidt P, Moors EJ, Naudts K, Novick K, Otto J, Pilegaard K, Pio, CA, Rambal S, Rebmann C, Ryder J, Suyker, AE, Varlagin A, Wattenbach M, Dolman AJ (2014) Land management and land-cover change have impacts of similar magnitude on surface temperature. Nature Climate Change 4:389-393

Tölle, MH, Moseley C, Panferov O, Busch G, Knohl A (2013) Water supply patterns in two agricultural areas of Central Germany under climate change conditions, Biogeosciences, 10, 2959-2972

Knohl A, Baldocchi DD (2008) Effects of diffuse radiation on canopy gas exchange processes in a forest ecosystem. Journal of Geophysical Research-Biogeosciences, 113: G02023

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Detailed description of the work plan

In this TP, we will test the following working **hypotheses**:

H1 Evapotranspiration from agroforestry differs in magnitude and temporal dynamics relative to evapotranspiration from mono-specific agricultural crops under comparable climatic and soil conditions,

H2 Strips of trees interleaved with agricultural crops of lower height affect the local wind field and therefore influence atmospheric controls of water fluxes on adjacent crops,

H3 Spatial variability of yield production from agricultural crops in agroforestry systems is influenced by the combined effects of competition for light between trees and agricultural crops (shading by trees), wind modification (sheltering effect of trees, reduction of soil erosion, control on evapotranspiration),

H4 Management parameters (width, orientation, spacing, and rotation duration, i.e. age of tree components) act as controls on water fluxes and drivers of soil erosion potential (local wind conditions) in agroforestry systems,

H5 Realizations of actual system responses along a range of potential responses does depend on site specific climatic and soil conditions, e.g. improved crop yield due to wind sheltering effects and reduction of soil erosion risk will be more pronounced on windy sites with easily erodible soils and will also depend on crop type (stronger impact of wind sheltering effects on agricultural crop yields than on grassland yield) in agroforestry systems.

In order to test above hypotheses the atmospheric component of TP1 will conduct the following field **measurements**:

- Deploy ten eddy covariance turbulent flux towers (Aubinet 2000, Foken 2008) across all sites (in total 5 agroforestry sites and 5 reference sites at Dornburg, Forst/Lausitz, Wendhausen, Reiffenhausen, Mariensee) to continuously measure total ecosystem evapotranspiration from agroforestry and from the references, using the eddy-covariance-energy-balance technique (ECEB, Bernhofer et al. 1996). Each tower, which is up to 10 m high, will be equipped with a 3-dimensional sonic anemometer (Metek Inc, Germany) to measure horizontal and vertical wind velocities and temperature at a 20 Hz frequency. Those data will be used to derive directly turbulent fluxes of sensible heat and estimate water vapour fluxes based on the energy balance (see meteorological measurements below).

- Deploy ten sets of meteorological instruments at the ten eddy covariance flux towers to continuously measure meteorological drivers of water vapour fluxes and sensible heat fluxes (i.e. global radiation, net radiation, soil heat flux, air temperature, relative humidity, precipitation, wind velocity, wind direction). Soil variables (volumetric soil water content, soil temperature) will be provided by the central services of TP1-1.

- Conduct repeated field measurements of crop and tree specific controls of transpiration (stomatal transfer resistances and transpiration rates) by porometry (Li-1600, LI-COR, Lincoln, USA) throughout the growing season (porometer measurements in close collaboration with TP3-2).

TP1-2 will integrate above field measurements into two **models**:

We will use a two-layer soil-vegetation-atmosphere transfer (SVAT) model of the Shuttleworth-Wallace type (Shuttleworth and Wallace 1985) to

- Calculate individual components of evapotranspiration (soil evaporation, interception evaporation, transpiration),

- Partition evapotranspiration fluxes into tree- and crop components, separately,

- Up-scale local point measurements (porometer measurements) in space and time,

- Deliver spatially and temporally continuous products of evapotranspiration to the consortium (TP8, TP7, TP2), constraining estimates of root water uptake (TP3-2),

- Couple the atmospheric SVAT model to the soil water model used by TP1-1 to calculate the drainage flux,

- Model radiation competition between trees and crops using simple geometric relations.

Vegetation specific controls of evapotranspiration in the SVAT model (stomatal resistances) will be parameterized through measurements of transpiration and stomatal resistances of trees and crops at the leaf scale as well as Leaf Area Index measurements. Those measurements will be performed regularly throughout the growing seasons (in collaboration with TP3-2) using two mobile water vapor porometers and mobile LAI meters.

Atmospheric controls in the SVAT model (turbulent atmospheric transfer resistances) will be parameterized through coupling of the SVAT model with a 3D wind and turbulence model. This computational fluid dynamics model is a Large Eddy Simulation (LES) model (Popinet, 2003, Griessbaum 2009, Giessbaum 2010) which predicts the 3-dimensional wind field at high spatio-temporal resolutions while accounting for the complex geometry of agroforestry with strips of trees and their impact on local wind fields.

The 3-dimensional wind velocity fields and atmospheric turbulence parameters derived from Large Eddy Simulation (LES) modeling will be used in order to:

- Parameterize the SVAT model for spatial up-scaling (via wind speed and turbulence),

- Investigate interactions of trees and crops through detailed simulations of sheltering and wake effects from the tree crop boundary to open crop areas between trees (erosion risk),

- Complement the crop and soils modelling platform of TP8 with an atmospheric water fluxes modeling environment to simulate the impact of a range of management options (tree and crop size, spacing, orientation and tree height) on the wind field and subsequently on evapotranspiration fluxes.

Verwertungsplan

TP1-2 liefert über die Ergebnisse aus den Feldexperimenten und entsprechende Modellsimulationen die wissenschaftlichen Grundlagen zum erweiterten Verständnis des Wasserhaushalts von Agroforst-Systemen. Dabei steht die gegenseitige Beeinflussung der Verdunstungsleistung der Acker- und Baumanpflanzungen im Vergleich zum jeweiligen konventionellen, monokulturellen Anbau (nur Acker, nur KUP) im Vordergrund der Betrachtungen. Hinsichtlich der Umsetzung der Ergebnisse soll über praxistaugliche Modellszenarios getestet werden, unter welcher jeweils standortsbezogenen Variante der agroforstlichen Anwendungen (z.B. räumlicher Anordnung, Mischungsverhältnis von Bäumen und Ackerfrüchten etc.) die größtmögliche Vorteilswirkungen im Vergleich zur monokulturellen Bewirtschaftung erzielt werden kann. Weiterhin dienen die Ergebnisse des meteorologischen APs als Grundlage zur Berechnung von Stoffflüssen (TP1-1) und Ertragsleistungen (TP4 - TP7) und liefern somit die Grundlage zur AP-übergreifenden Modellierung mittels Expert-N und YieldSAFE in TP 8.

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TP1-2 (Knohl & Siebicke)	The influence of AF on evaporation and transpiration											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student and student assistants for field installations) **(M)**												
Installation of turbulent flux towers with ancillary meteorological measurements (radiation, soil heat flux, humidity, temperature, precipitation) completed **(M)**												
Start of stand scale turbulent fluxes analysis (evapotranspiration) routines, functional quality assessment and quality control procedures **(M)**												
Turbulent flux evapotranspiration rates data checked and transfer to modelling TP (7,8) and to the database of the Bonares-Centre **(D)**												
Start of stomatal conductance and transpiration measurements **(M)** and data transfer to modelling TP (7,8) and to the database of the Bonares-Centre **(D)**												
Start of fieldwork on measurements of energy balance partitioning for evapotranspiration rates **(M)**												
Start of SVAT modelling of trees and crops, 3D wind modelling **(M)** and data transfer to modelling TP (7,8) and to the database of the Bonares-Centre **(D)**												
Annual project meeting **(M)** and annual / final reports **(D)**												
Manuscript on (1) Water use of agroforestry systems. and (2) Modeling 3D wind fields and radiation in agroforestry systems written and submitted **(D)**												

TP2-1 Diversity and activity of soil organism communities as indicators of sustainable land use

Principal Investigators: Christine Wachendorf[1], Martin Potthoff[1] and Rainer Georg Jörgensen[1]

[1] University of Kassel, Department of Soil Biology and Plant Nutrition

Scientific background and current status of research; previous work

Evaluating soil fertility is still a challenge which is due to a lack of evaluation of suitable methods applicable for a wide array of soils and also due to spatiotemporal variation of many of microbial properties (Joergensen and Emmerling, 2006; Creamer et al., 2009, 2014; Ritz et al., 2009). Agroforestry directly affects the soil environment via changes in microclimate, soil water quality and quantity as well as quality of litter. Therefore, agroforestry has an impact on soil organisms mediating ecosystem services such as decomposition of organic matter, nutrient provision, and C sequestration. Due to the multiform land use of agroforestry, activity of soil organisms and turnover of SOM varies in time and space. Nevertheless this effect of heterogeneity on microbial and earthworm activity with its impact on soil nutrient dynamics analysed in TP1 has not been analysed before. The beneficial effects of plant diversity on ecosystem stability are undisputed (Tilman and Downing, 1994), whereas the relationship between aboveground and belowground diversity is still under debate and the links between diversity of soil microorganisms and soil functioning are poorly understood (Griffiths, and Philippot, 2013). Incongruent results were reported as some studies observed a positive relationship of plant diversity and soil microbial functional diversity (Liu et al. 2007; Zak et al. 2003), whereas others found no relationship (Habekost et al., 2008; Marshall et al., 2011). Plant effects on soil microbial communities may also be superimposed soil factors like pH, SOC content and moisture availability (Brimecombe et al., 2007; Marschner et al., 2004). Harrison and Bardgett (2010) and Andruschkewitsch et al. (2014) found that abiotic soil factors were much more important drivers of soil microbial properties than the presence of various plant species. Also temporal dynamics in quantity and quality of plant resources (root exudates and litter) are known to influence soil microorganisms during plant development (Brimecombe et al., 2007). We therefore postulate that plant diversity in the grassland site at Reiffenhausen may affect functional diversity of soil microorganisms depending on the dynamics of abiotic factors (e.g. soil water content and soil pH) as well as biotic factors like quality and quantity of litter, which are both influenced by distance of the tree line. This project addresses biomass, microbial residues, activity and functional diversity of soil organisms, providing multiple soil functions. The objective of the study is to track spatial heterogeneity of soil microorganisms and earthworms in soils under grassland and arable cropping with differing distances from the treeline in agroforestry ecosystems. The importance of microorganisms and earthworms for ecosystem services as well as the interactions between biological and abiotic factors will be elucidated.

Preliminary work and previous achievements of the applicants

Christine Wachendorf, Rainer Georg Jörgensen and Martin Potthoff have broad experience in interdisciplinary soil biological and soil ecological research. The scientists have many years of extensive experience in interdisciplinary soil biological and soil ecological research in soils from different land-use systems, i.e. in forest, grassland and arable systems. The focus of the work of Christine Wachendorf is on evaluation of the effect of management and land-use changes on microbial mediated C and N dynamics in soils under grassland and short rotation coppices (Andruschkewitsch et al., 2014, Toenshoff et al, 2013a, b). Microbial immobilization as well as differentiation between decomposition of organic matter and added residues were elucidated by ^{15}N labelling and application of ^{13}C natural abundance methods (Wachendorf and Joergensen, 2011, Wachendorf et al., 2014). Rainer Georg Jörgensen's research has a strong focus on measuring microbial activity, microbial biomass (C, N, P, and S), and microbial residues (amino sugars) especially for investigating the effects of stress on soil microorganisms (protons, pesticides, heavy metals, and salinity), using stable isotopes (15N and 13C) (Lukas et al., 2014). Martin Potthoff works on soil fauna (mainly earthworms) and soil microorganisms, their interactions, and the impact of land use on soil biota and vice versa. Ecosystem services provided by soil organisms as keystones for sustainable land management are the main drivers of his research.

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Toenshoff C., Joergensen, RG., Stülpnagel, R, Wachendorf C. 2013a. Carbon in plant biomass and soils of poplar and willow plantations – implication for C distribution after re-conversion to arable land. Plant Soil 367: 407–417

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Wachendorf, C, Joergensen, RG. (2011): Mid-term tracing of ^{15}N derived from urine and dung in soil microbial biomass. Biology and Fertility of Soils 47: 147-155

Wachendorf, C., Potthoff, M., Ludwig, B., Joergensen, R.G. 2014. Effects of addition of maize litter and earthworms on C mineralization and aggregate formation in single and mixed soils differing in soil organic carbon and clay content. Pedobiologia 57: 161-169

Detailed description of the work plan

We measure the effect of trees at all agroforestry sites and the diversity of grassland at the site of Reiffenhausen on activity and functional diversity of soil microorganisms. Therefore we take soil samples at all sites (5 sites) and replicate plots (4) at 0, 1, 7 and 24m distance from the tree strips (4 distances), in total 5 x 4 x 4 = 80 locations and at the control sites (5 sites x 4 replicates plots = 20 locations). In addition at the site Reiffenhausen, samples will be taken in two grassland types (white clover mixtures and grassland with 32 species) (4 replicate plots * 4 distances + 4 control plots = 20) and also on the arable site (4 replicate plots * 4 distances + 4 control plots = 20). Timing of the sampling will be coordinated with TP1-1 (Veldkamp, Lamerdorf, Corre) and TP3-1 (Kuzyakov & Jansen). In particular we will analyze indices for microbial activity (basal respiration, community-level physiological profiling (CLPP) by multi-SIR (substrate-induced respiration) (Andruschkewitsch et al., 2014) and selected enzymes important for the N-mineralization, as well as microbial biomass (ergosterol, C, N) (Toenshoff et al., 2014), and microbial residues (amino sugars: glucosamine (GlcN), galactosamine (GalN), mannosamine (ManN), and muramic acid (MurN))(Murugan et al., 2014). Investigations of functional diversity will be repeated in 2016. Soil samples will be taken in the upper and lower layer of the top soil under arable, coppice and grassland land use. Furthermore litter decomposition of ^{13}C and ^{15}N labelled coppice leaves and grassland plants will be conducted (Langenbruch et al., 2014). Pulse labelling of litter will be conducted in the second year together with TP3-1. Decomposition will be calculated by recovery rates of ^{13}C and ^{15}N in soil, and particulate organic matter. Pulse labelling may cause a dissimilar label different fractions of organic matter, therefore labelling will be checked by ^{13}C analysis of soluble organic C, cellulose and lignin fraction. Earthworms will be sampled in different frequencies at the different sites (Metzke et al., 2007). Individuals will be identified on the species level and weighed. Focal observation site for this part is Reiffenhausen. Here, plots will be sampled twice a year in spring and late autumn. At all other sites earthworms will only be studied once within 3 years. Results will contribute to the overall analysis of agroforestry by providing data to estimate the ecosystem services mediated soil organisms as a factor of sustainable food production. We imply that recent changes in abiotic as well as biotic factors occurring with distance from trees are mirrored in microbial activity. Consequently, TP2-1 provides a comprehensive approach on soil microbial indices and captures fast and slow turnover processes by combining multiple methods. Furthermore the common interpretation of highly fluctuating data like soil water plant biomass and microbial activity enables a comprehensive evaluation of effects of land use.

Verwertungsplan

Die Arbeiten des TP2-1 werden einen Einblick in die komplexen und bisher nur unzureichend untersuchten Zusammenhänge zwischen bodenbiologischer und oberirdischer Aktivität und Diversität sowie deren Rückwirkungen auf den Ertrag liefern. Dabei steht auch hier die Beeinflussung durch die zusätzliche Baumkomponente mit ihrer biotischen (z.B. Streuinput) und abiotischen (Licht, Wasser) Wirkung im Vordergrund der Untersuchungen. Mögliche Vorteilswirkungen (zusätzliche Anreicherung von C im Boden) werden im Hinblick auf die Ertragssteigerung von Ackeranbauten und andere ökologische Dienstleistungen (C-Sequestrierung, Klimaschutz) quantifiziert. Als Ergebnis werden praxisrelevante Anwendungsempfehlungen sowie Möglichkeiten zur Indizierung der bodenbiologischen Vielfalt geliefert.

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TP2-1 (C. Wachendorf, Potthoff & Jörgensen)	Diversity and activity of soil organism communities											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student and student assistance for field installations) **(M)**												
Soil sampling and start soil analysis of microbial activity, microbial biomass and microbial residues **(M)**												
Earthworm sampling and identification **(M)**												
Soil analysis of microbial activity and earthworm abundance completed and data transfer to modelling TP (7, 8) and to data base of BonaRes-Centre **(D)**												
^{15}N labelling of plants (labelling period synchronized with labelling of plants in $^{13}CO_2$ atmosphere; see TP3-1) **(M)**												
Start of fieldwork on litter decomposition and analyses of labelled litter **(M)** and data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Start of microbial and earthworm diversity investigations in two agroforestry grass-lands systems with differing plant biodiversity **(M)**												
Transfer of data microbial and earthworm diversity to modelling TPs (7,8) and to data base of BonaRes-Centre **(D)**												
Annual project meeting **(M)** and annual / final reports **(D)**												
Manuscript on (1) microbial and earthworm activity and (2) litter decomposition efficiency written and submitted **(D)**												

TP2-2 Management effects on above-ground matter fluxes in silvopastoral systems

Principal Investigator: M. Wachendorf[1]

[1] University of Kassel, Dept. of Grassland Science and Renewable Plant Resources

Scientific background and current status of research; previous work

Conventional grassland management is often characterized by low biodiversity, high cutting frequency and high fertilization rates. At the same time, extensive grassland with higher biodiversity is often threatened by abandonment (Isselstein et al., 2005) especially in lower mountain areas, due to low productivity, less feed quality and the reduction of animal husbandry (Khalsa et al., 2014). Depending on the location, agroforestry systems have been shown to contribute to a sustainable agriculture (Quinkenstein et al., 2009, Tsonkova et al., 2012). Agroforestry systems with grassland and trees could be a promising strategy for combining high productivity while maintaining ecosystem services, like increased biodiversity, regulating soil and water quality preservation of grassland, reducing competition between food or feed and energy production (Smith et al., 2012).

However, until now the short- and middle-term effects of different grassland types in combination with willows (as short rotation coppice, SRC) on crop development, biomass yield and several soil parameters (e.g. nutrient fluxes (with TP1-1), microbial activity (with TP2-1)) are unknown (Ehret et al., 2014), even though these parameters are essential for N- and P-response efficiencies and water use efficiency. As these parameters will be directly influenced by field management, by biomass yield of the crops and by organic residues, such as leaf litter production from the willows in the border areas of the grassland strips considering competition effects (Benjamin et al., 2000), TP2-2 will analyse several management strategies of grassland (Table 2) in cooperation with other TPs regarding the effects on the above-mentioned parameters of the system, as well as on socio-economic effects (TP4-2). Furthermore, the experiment will provide important data for the parameterization of growth models in TP 8.

The objective of this TP is to study the combined effect of tree/grassland sward competition and different grassland management treatments in a silvo-pastoral system on the tree (wood) and sward growth and on the above-ground leave biomass from the trees.

Preliminary work and previous achievements of the applicants

Michael Wachendorf´s research focus is on the improvement of forage- and biomass production systems considering productivity and environmental impacts. His academic interests are to understand the effects of climate, land-use systems and management practices on the productivity and quality of crops for animal feeding and energetic use and on the impact of various energetic conversion techniques on the preservation of species rich semi-natural grasslands. He has established the agroforestry system in Reiffenhausen in 2011, which combines willow trees and various grassland systems in an alley cropping design and has researched this system since then. Furthermore, he investigated the establishment of short rotation coppices and the reconversion of them into arable land or grassland.

5 most important references:

Wachendorf, M., F. Richter, T. Fricke, R. Graß, and R. Neff. 2009. Utilisation of semi-natural grassland through an integrated generation of solid fuel and biogas from biomass I: Effects of hydrothermic conditioning and mechanical dehydration on mass flows of organic and mineral plant compounds, and nutrient balances. Grass Forage Sci. 64(2): 132–143.

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Detailed description of the work plan

Research activities of TP2-2 will be conducted in the silvo-pastoral agroforestry system in Reiffenhausen (Germany, county Göttingen; established in 2011), combining grassland and willows in an alley cropping design. Grassland biomass will be used both for animal and energy production, willows will be used as short rotation coppices for energy production. Tab. 2 shows the grassland treatments tested in this task. Pure willow and grassland stands of each treatment serve as a control and will be investigated for further analysis, such as land equivalent ratio (together with TP7).

Aboveground biodiversity will be analysed by determining the plant functional groups (i.e. grasses, herbs, legumes), as well as number and abundance of single plant species in each treatment, for which an intensive collaboration with TP4-1 is planned.

Table 2: Treatments tested in the silvo-pastoral experiment (with three replicates)

Factor 1 **Grassland mixture**	**Factor 2** **Cutting intensity**
• White clover/grass mixture • Mixture with 32 species	• 2 cuts per year • 4 cuts per year

TP2-2 will analyse the biomass (dry matter yield and -content) and quality of grassland (according to Naumann and Basler, 1993: Weende analysis, detergent fibre, enzymatic digestibility) and the annual dry matter growth of willows: estimating DM-yield of willows by measuring diameter increment at breast height (1.30 m) and tree heights. Furthermore fuel characteristics of willows will be analysed according to Friedl et al (2005).Three ways of energetic conversion of grassland biomass will be conducted: 1) Whole crop digestion of grassland biomass; 2) IFBB-technology (Wachendorf et al., 2009) with biogas and solid fuel production from grassland biomass and 3) Hay combustion. Energetic assessment of willows will be conducted by determining the heating value and ash characteristics (Friedl et al., 2005). For analyses of energetic aspects composite samples of the replicates from each treatment will be investigated. A detailed description is given in the AZA template.

Energetic parameters serve as basis for conduction of energy balances for each treatment (including control treatments) which enables a direct comparison.

In agroforestry systems there is a substantial input of organic residues (leaves and roots) from SRC to the grassland. This may eventually have an influence on the aboveground and soil microorganism´s diversity in the grassland. For the assessment of this input amount and spatial allocation of willow leaves will be investigated. During the whole period of litterfall the total amount of litter per square meter plots will be assessed. To analyse the spatial distribution of tree litter, traps will be placed along transects into the grassland stripes as well as directly within the tree strip.

Together with TP1-1, central services, two different measurement areas will be established:

1) According to the basic design for each SIGNAL site above mentioned yield and energy parameters will be measured.

2) Transects will be established in the grassland stripes (9m width) among the willow alleys in each of the treatments. Along this transect sampling plots will be determined at a distance of 1m for measuring dry matter yield and -content of grassland biomass and for determining plant functional groups (i.e. grasses, herbs, legumes).

The experiment will be conducted during two growing seasons.

Investigations will be conducted by the requested PhD-student, which will be supported and supervised by Dr. Rüdiger Graß, scientific research assistant of the department. Dr. Graß will also organise the grassland management and sampling activities on the agroforestry site in Reiffenhausen, for which costs of a 0.25 personnel position are requested for the first experimental year.

Verwertungsplan

Die Arbeiten des TP2-2 liefern die Basis zur Ableitung von Bewirtschaftungs- und Verwertungsstrategien für Grünland-Agroforstsysteme mit KUP. Dazu zählen u.a. der Einsatz verschiedener Grünland-Artenmischungen, unterschiedliche Ernteintervalle sowie die Düngung und die Umsetzung und Verwertung von Residualstoffen (Blätter, Streu) sowie entsprechende Rückwirkungen auf die Qualität und den Ertrag. Auch hier dient als Referenz die klassische, monokulturelle Grünlandbewirtschaftung. Der zweite Fokus von TP2-2 liegt bei der Überprüfung und Weiterentwicklung innovativer Verfahren zur energetischen Verwertung des anfallenden Grünschnitts (Biogas, Festbrennstoff), einschließlich der Ableitung von Energiebilanzen. Insbesondere im Zusammenspiel mit der ökonomischen Bewertung (TP4-2) bilden Energiebilanzen den Zugang zur übergreifenden Modellierung und zur Übertragbarkeit auf andere Standorte und Systemvarianten. Ferner liefert TP2-2 wichtige Datengrundlagen für die Modellierungsvorhaben von TP7 und TP8 sowie für die Auswertungs- und Umsetzungsansätze im BonaRes Zentrum.

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TP2-2 (M. Wachendorf)	**Above-ground matter fluxes in silvopastoral systems**											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student and student assistance for field installations) **(M)**												
Preparation and installation of sampling areas and transect **(M)**												
Start of continuous grassland biomass harvest **(M),** yield determination finished **(D)**												
Start of continuous grassland quality and leave biomass determination **(M)**												
Start of continuous methane content analysis of harvested grassland biomass and determination of annual dry matter growth of willows **(M)**												
Provision of whole biomass yields and qualities and energy balances, data transfer to modelling TP8 and to data base of BonaRes-Centre **(D)**												
Annual project meeting **(M)** and annual / final reports **(D)**												
Manuscripts on (1) yield and quality and (2) energy yields and balances written and submitted **(D)**												

TP3-1 Carbon pools and fluxes in the rhizosphere of agroforestry systems

Principal Investigators: Yakov Kuzyakov[1] and Martin Jansen[2]

[1] University of Göttingen, Agricultural Soil Science

[2] University of Göttingen, Soil Science of Temperate Ecosystems

Scientific background and current status of research; previous work

Organic substances translocated by plant roots into the soil are the main source of carbon (C) and energy for microorganisms responsible for most biochemical reactions, including mobilization of nutrients from hardly available sources, e.g. soil organic matter (SOM), clay minerals, sesquioxides. The other energy sources, e.g. oxidation reactions or some chemical reactions of inorganic compounds are negligible compared to the energy bound in plant derived organic substances. Therefore, knowledge of the amounts and localization of organic substances added by plant roots into the soil and especially into subsoil is crucial for evaluating many soil processes including mobilization of nutrients (Kautz et al. 2013).

The amount of C input by roots including rhizodeposition into soil was reviewed earlier for agricultural crops (Paul and Clark 1996; Kuzyakov and Domanski 2000; Amos and Walters 2006) and grassland plants (Redmann 1992; Kuzyakov and Domanski 2000). However, studies on C input by trees and especially short rotation coppices are absent. All mentioned reviews and most original studies considered mainly the C input within the upper ~ 30 cm of the soil. The C input into deeper soil horizons remains mainly unconsidered.

Important difference of agroforestry systems compared to agricultural crops is the presence of multiple interactions between the roots of perennial trees with annual crops or biannual grasses (for grassland). This leads to spatial and temporal niche differentiation in soil including interactions with various microbial groups and for acquisition of water and nutrients (Kuzyakov and Xu 2013). Consequently, higher nutrient use efficiency may be achieved not only by better spatial distribution of roots, but also by various interactions between roots and microorganisms leading to higher microbial activity and C sequestration.

The objectives of the study are:

- Analysis of pools and fluxes of C in soil under short rotation coppice systems.
- Analysis of activity and kinetics of enzymes responsible for C, N, P and S cycles depending on depth and distance from the short rotation coppice strip.
- Assessment of composition of microbial groups depending on depth and distance from the short rotation coppice strip.
- Estimation of C input by roots and rhizodeposition into soil for young trees, grasses and crops.
- Delivery of parameters of C pools and fluxes as well as microbial composition and activity for modelling.

Preliminary work and previous achievements of the applicants

Yakov Kuzyakov has a long-term experience in studying C and N cycles with special focus on rhizosphere. Application of ^{14}C, ^{13}C, $\delta^{13}C$ and ^{15}N allowed to analyse various rhizosphere processes: rhizodeposition and its decomposition, amount and composition of C released by root of various plants, turnover of nutrients and their uptake by plants. The ^{14}C and ^{13}C labelling of plants that is one of the key methodologies to be applied in this project is widely used in the applicant's group (Spohn & Kuzyakov 2014; Pausch et al. 2013). To analyse root derived C in soil, the images of ^{14}C distribution in shoots and roots showed hotspots in the rhizosphere and the distribution of meristem zones in shoots and roots and their different growth rates (Pausch & Kuzyakov 2011.). Recently a new approach to analyse effects of roots on microbial activities and to evaluate special distribution of enzyme activities was developed (Spohn & Kuzyakov

2014). Analyses of enzyme activities responsible for C, N, P and S cycles are standard approaches in the group (Sanaullah et al. 2011). Similar approaches will be used in this project.

The experiences of Martin Jansen are in the field of water resources of forests and short-rotation coppices (e.g. projects BEST, KLIFF, DSS-WuK). The focus was on risk assessments regarding drought due to climate change and hazards of the landscape water and matter balance through the cultivation of fast-growing trees. He has experience in both construction and operation of field stations and in the modelling of plot and landscape scale.

5 most important references:

Pausch, J., J. Tian, M. Riederer, and Y. Kuzyakov. 2013. Estimation of rhizodeposition at field scale: upscaling of a 14C labeling study. Plant and Soil 364:273-285.

Pausch, J., and Y. Kuzyakov. 2011. Photoassimilate allocation and dynamics of hotspots in roots visualized by 14C phosphor imaging. Journal of Plant Nutrition and Soil Science 174:12-19.

Sanaullah, M., E. Blagodatskaya, A. Chabbi, C. Rumpel, and Y. Kuzyakov. 2011. Drought effects on microbial biomass and enzyme activities in the rhizosphere of grasses depending on plant community composition. Applied Soil Ecology 48:38-44.

Spohn, M., and Y. Kuzyakov. 2014. Spatial and temporal dynamics of hotspots of enzyme activity as affected by living and dead roots – A soil zymography analysis. Plant and Soil 379:67-77.

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Detailed description of the work plan

Carbon pools fluxes and microbial activities

The study consists of four parts. The first part is focused on the analysis of potential activity and kinetics of enzymes responsible for C, N, P and S cycles. The second part will analyze the composition of main microbial groups in soil under various components of agroforest. The third part aims to assess the C input by young trees, crops and grasses and to analyze their contribution to C sequestration under agroforest components. Part 4 will be focused on formalization of the parameters obtained within the three experimental parts to deliver the process rates and pools for modelling. The sampling time and locations will be coordinated with other TPs (TP1-1 Veldkamp et al., TP2-1 Wachendorf & Joergensen, TP3-2 Carminati & Jansen).

Part 1: Activities of enzymes will be analyzed in all experimental plots of SIGNAL: Phenol oxidase and peroxidase (lignin decomposition), Xylanase (hemicellulose decomposition), Cellobiohydrolase (early stage of cellulose decomposition), β-glucosidase (last stage of cellulose decomposition), Chitinase (chitin decomposition), Phosphatase (split phosphate from organic molecules), Sulfatase (split sulphate from organic molecules). These enzymes are responsible for C, N, P and S cycles and so, reflect the potential for nutrient mobilization from soil organic matter (Blagodatskaya and Kuzyakov 2008). The enzyme activities and kinetics will be determined using fluorogenically labeled substrates (Pritsch et al. 2004). The method is established in the group of the applicants (Dorodnikov et al. 2009; Sanaullah et al. 2011). Microbial biomass C and N will be analyzed in the same samples. The analyses will be done in 0-30 cm (plow-layer), 30-60 cm and 100 cm depths (see experimental core design, Fig. 3 of the General Part).

Part 2: Analysis of microbial groups present under various components of short rotation coppices will be done by composition of phospholipid fatty acid (PLFA) approach (Apostel et al. 2015). This will be done in the plots of the field-site in Reiffenhausen. This 2nd part is necessary to characterize the gram positive and gram negative bacteria, saprophytic and arbuscular mycorrhiza fungi, actinomycetes and protozoa under different parts of agroforestry systems to conclude about the effects C, nutrients and water budget on microbial composition in soil. The analyses will be done for soil samples from 0-30 cm (plow-layer), 30-60 cm (subsoil) depths at increasing distance from the short rotation coppices (see experimental core design, Fig. 3 of the General Part).

If the ^{13}C labeling of plants (see part 3) will have sufficient ^{13}C input and incorporation into microbial groups, the ^{13}C incorporation into individual PLFA will be traced. This will allow to conclude about main microbial groups responsible for utilization of root derived C and their relative activities.

Part 3 will assess the C input into soil by various components of short rotation coppices. The ^{13}C pulse labeling will be conducted under field conditions (Riederer et al. 2015). Small trees of short rotation coppices, crops and grassland will be labeled within the main plots of the experimental core design (Fig. 3 of the General Part). Subsequently, ^{13}C will be analyzed in various soil compartments including microbial biomass, dissolved organic C, rhizosphere and non-rhizosphere soil (only Reiffenhausen). The soil will be sampled down to 1 m depth. To evaluate the C input by rhizodeposition, we will use the recently developed approach of rhizodeposition/root ratio from laboratory ^{14}C labeling (Pausch et al., 2013). For this aim the labeling of the same plants as in the field will be conducted under controlled conditions, and the decomposed rhizodeposits will be traced by trapping of $^{14}CO_2$. The remaining ^{13}C labeled litter from the WP3 will be used by the TP2-1 (Joergensen & Wachendorf) for litter decomposition studies. Within this WP the amount of roots and soil organic matter in various soil depths under short rotation coppices, crops and grassland will be estimated to conclude about the potential of components of agroforestry not only for C allocation, but also for nutrients and water uptake.

Part 4: formalize the results of parts 1-3 and deliver pools and flux parameters for modelling. Finally, the results from the first 3 parts as well as from will be joined to the analysis of the broad range of effects of tree roots on soil C content, turnover of microorganisms, microbial mobilization of and nutrients and C and the effects of various parts of agroforestry systems on microbial communities.

Verwertungsplan

Das TP3-1 liefert über differenzierte Erkenntnisse zur Verteilung und Aktivität von Enzymen, Pilzen und Bakterien Hinweise zur Beeinflussung und Steuerungsmöglichkeiten des Bodenlebens durch Agroforstsysteme. Dabei konzentrieren sich die Arbeiten des Projektes auf den wurzelnahen Bereich (Rhizosphäre) und mögliche Veränderungen von Stoffflüssen (C, N, P) unter Berücksichtigung der räumlichen Verteilung der abiotischen Bedingungen (Licht, Wasser) und dem ober- und unterirdischen Wachstum der Ackerkulturen im Abstand von den KUP-Streifen. Ein besonderer Fokus liegt in der Analyse der Baumwurzelrhizosphäre und deren Einfluss u.a. auf die Bodenfruchtbarkeit, den Wasserhaushalt (TP3-2) und die C-Sequestrierung. Über entsprechende Modellierungen sollen Bewirtschaftungsstrategien erarbeitet werden (z.B. Pflanzdichten- und Abstände, mögliche Wurzelschnitte entlang von Baumstreifen, Streuverwertung).

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TP3-1 (Kuzyakov & Jansen)	**Carbon pools and fluxes in the rhizosphere of agroforestry systems**											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student, student assistance for field installations) (**M**)												
Sampling of soil for analyses of enzymes and microbial biomass (**M**)												
Preparation of the sites for analyses of enzymes activities completed(**M**)												
Microbial biomass content, enzyme activities and distribution identified and data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Preparation of the sites and labelling of plants in $^{13}CO_2$ atmosphere. Sampling of soil and plant materials with increasing time after the labelling (**M**)												
Identification of the most important parameters needed to understand the plant and soil hydrology in agroforestry systems, communicated to stakeholders (**D**)												
Assessment of the C input into soil by various plants under controlled and field conditions, conclusions for stakeholders (**D**)												
Annual project meeting (**M**) and annual / final reports (**D**)												
Manuscripts on (1) composition of microbial communities and (2) enzyme activities written and submitted (**D**)												

TP3-2 Soil hydrology and rhizosphere processes in agroforestry systems

Principal Investigators: Andrea Carminati[1] Martin Jansen[2]

[1] University of Göttingen, Soil hydrology
[2] University of Göttingen, Soil science of temperate ecosystems

Scientific background and current status of research; previous work

Crop production has to increase by 50 to 100% during the next decades to feed the growing world population (Gregory and George 2011). One of the major constraints to increasing crop production is water scarcity (Sposito 2013). Increasing irrigation would have adverse ecological impact and might not be efficient, as most of the water taken up by crops is water stored in soil after precipitation. An alternative strategy consists in optimizing the productive green water. Green water is the volume of water that is stored in soils after precipitation and that it is potentially available to plants (Sposito 2013). Green water is controlled by the soil hydraulic properties, which depend on soil texture, soil structure and organic content. The fraction of green water that is actually taken up by plant roots to sustain transpiration and photosynthesis is called productive green water. Increasing the productive green water would allow to increase yield and sustain it during drought.

For an efficient and sustainable use of water resources in agriculture it is critical to maximize the productive green water. This goal can be achieved through e.g. reducing water losses due to run-off, excessive drainage and evaporation from bare soil. In recent years, it has been shown that green water and soil properties are actively and dynamically modified by plants, e.g through root exudation and root growth. These plant-soil interactions result in complex feedbacks between soil and plants (Gregory 2006; Carminati and Vetterlein 2013). Carminati and Vetterlein (2013) reviewed how root exudates modify the soil surrounding the roots, the so-called rhizosphere, and how these soil modifications play a central role in the capacity of plants to adapt to the varying soil conditions. In particular mucilage exudation was suggested to help plants to take up water in dry soils and to better tolerate drought.

An additional mechanism having the potential to increase productive green water results is hydraulic redistribution. Hydraulic redistribution (HR) is the transport of water from wet soil layers to dry soil layers through the root system. HR is a passive mechanism driven by gradients in water potentials and it typically takes place when transpiration is low – i.e. during night (Burgess et al. 1998; Caldwell et al. 1998). The transport of water from the subsoil to the upper soil layers via deep-rooted plants is called “Hydraulic lift” (HL). Liste and White (2008) discussed the implications of hydraulic lift for crop production and land restoration. They suggested that HL acts as a biological subsurface sprinkler and provides additional water to the roots exposed to soil drying. Additionally HL has positive effects on nutrient uptake and rhizosphere biology. Liste and White (2008) concluded that HL may be a sustainable alternative to conventional irrigation techniques.

Agroforesty systems offer unique and diverse possibilities to optimize water resources available for plants. Trees reduce the exposure to wind and the evapotranspiraton demand in crops, resulting in slower water losses which can be beneficial during summer drought spells. Caldwell and Richards (1989) suggested that deep roots of trees can bring additional water to the top soil via hydraulic lift, providing a safety reservoir of water for shallow-rooted crops.

Our general goal is to quantitatively understand the aboveground and belowground factors controlling soil water distribution and transpiration rate in trees and crops and then to detect optimal tree-strip distances. Specifically, our objectives are: 1) To quantitatively determine the factors affecting the gradients in soil moisture below the crops as a function of distance from the trees. The factors that we will measure are: root water uptake by trees and crops and the competition in water uptake between their roots; wind reduction close to the trees; hydraulic redistribution during dry spells. 2) To measure the occurrence of hydraulic lift from deep-rooted trees to shallow-rooted crops and estimate how far this effect extends from the strips of fast growing trees. 3) To optimize the design of tree strip distances for varying trees, crops, soil properties and climate conditions.

Preliminary work and previous achievements of the applicants

The research fields of Andrea Carminati are soil hydrology and plant-soil interactions. In particular, the work of Carminati and co-workers focuses on the biophysics of the rhizosphere. In a series of papers Carminati (2010, 2012, 2013) demonstrated that the rhizosphere has distinct, hysteretic, and time-dependent properties that are significantly different from those of the adjacent bulk soil. Carminati's main hypothesis is that the rhizosphere physical properties play a central role in soil and plant water relations and control the flow of water along the different root segments. Recently, Carminati's group developed a method to trace the fluxes of water into roots and soils by means of neutron radiography and heavy water injection (Zarebanadkouki et al., 2013). In this proposed project this technique will be used to measure hydraulic lift in the field and in simplified laboratory experiments.

The experiences of Martin Jansen are in the field of water resources of forests and short-rotation coppices (e.g. projects BEST, KLIFF, DSS-WuK). The focus was on risk assessments regarding drought due to climate change and hazards of the landscape water balance through the cultivation of fast-growing trees. He has experience in both construction and operation of hydrological stations and in the soil water modelling at plot and landscape scale.

5 most relevant publications:

Carminati A, Moradi A, Vetterlein D, Vontobel P, Lehmann E, Weller U, Vogel H-J and Oswald SE. Dynamics of soil water content in the rhizosphere. Plant and Soil, 332: 163-176, 2010.

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Carminati A and Vetterlein D. Plasticity of rhizosphere hydraulic properties as a key for efficient utilization of scarce resources. Annals of Botany, 112 (2): 277-290, 2013.

Hartmann L, Richter F, Busch G, Ehret M, Jansen M, Lamersdorf L. Etablierung von Kurzumtriebsplantagen im Rahmen des Verbundprojektes BEST in Süd-Niedersachsen und Mittel-Thüringen–Standorteigenschaften und anfängliche Erträge. Forstarchiv 85: 134-150, 2014.

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Detailed description of the work plan

We plan to describe the soil hydrological behaviour at all sites of the core design where a special focus will be on the interactions between the strips of fast growing trees with the arable crops/grasslands. More intensive measurement focussing on specific processes (e.g. hydraulic redistribution, see below) will be conducted in the site of Reiffenhausen.

Soil Hydrological behaviour of agroecosystems will be intensively studied in the field-site of Reiffenhausen. The objective is to estimate the gradients in soil moisture as a function of distance from the tree lines at different depths. Our hypotheses are that: 1) the soil moisture content decreases as a function of distance from the tree lines due to the higher wind and evapotranspiration demand far from the trees; 2) despite this overall decrease in water content at increasing distance from the tree lines, in the first 2-3 meters near the trees, the soil moisture content decreases because of water uptake of tree roots; 3) leaf water potential is positively correlated with soil moisture content. Soil moisture and soil matric potential will be measured at different depths as a function of distance from the tree lines. Additionally, we will measure wind velocity, humidity and temperature at increasing distance from the tree lines. We plan a campaign to measure leaf stomatal conductance using a leaf porometer (Model Sc-1, Decagon) and leaf water potential using a Scholander pressure chamber method at specific times during the year. Additionally, during selected summer dry periods we plan to install ZIM-sensors (Bramsley et al. 2013) to continuously measure leaf turgidity. The measurements of stomatal conductance will be conducted together with TP1-2. Additionally TP1-2 plans to simulate the wind profiles as affected by trees. These simulations will be compared to our experimental results. We plan to measure soil moisture and soil matric potential at temporal resolution of 30 minutes in the field-site of Reiffenhausen. The measurement plan is illustrated in Fig. 4. For the other field locations we will use soil moisture data collected in TP1-1, central services according to the general experimental core design.

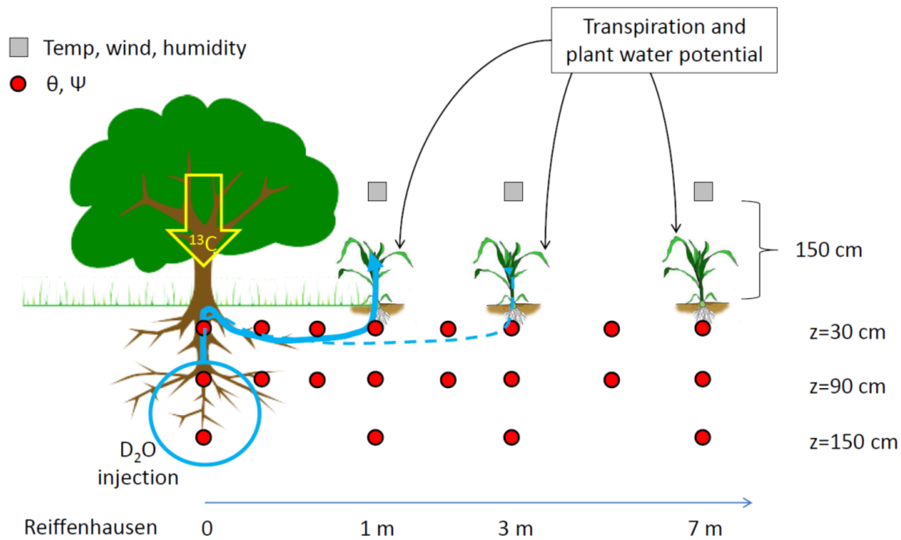

Fig. 4*: Spatial distribution of instruments for the field experiment in Reiffenhausen. This design follows the core design of the project. Here we will have a more resolved spatial resolution and we will add measurements in the top soil (depth of 30 cm).*

Hydraulic lift from trees to crops will be measured by injecting heavy water (D_2O) at depths of 90 cm and 150 cm and 210 cm below the tree roots. Soil water solution will be collected at depths of 30 cm at increasing distance from the trees using suction cups. Sap flow will be collected from excised crops at varying distance from the tree lines using a portable Scholander pressure chamber. The presence and concentration of heavy water will be measured at the KOSI laboratory of the University of Göttingen. Collection of D_2O from soil and trees will be done during day and night time at regular intervals. The measurements will be performed in Reiffenhausen under conditions in which hydraulic lift is expected to occur – i.e. when the water content at 30 cm depth is below 0.05, while the water content at 150 cm depth remains high. Our hypothesis is that D_2O will be transported from the subsoil below the trees to the shallow roots of crops by hydraulic lift. The injection of D_2O will be coordinated with the injection of ^{13}C (TP3-1)

The experiments with heavy water will be repeated in laboratory. We will make use of neutron radiography to image the transport of heavy water from tree seedlings to shallow-rooted crops according to the method developed by (Zarebanadkouki et al. 2012; Zarebanadkouki et al. 2014). An example of neutron radiography and our experimental set-up is shown Fig. 5. We plan to grow poplar seedlings in quasi-2D slabs of 100 cm x 100 cm x 2 cm filled with soil collected from the Reiffenhausen site. A layer of coarse sand in the middle of the sample will hydraulically disconnect the upper and lower parts of the soil profile. When the trees will have established a deep root system in the lower soil profile we will plant the crops plants. We will then inject D_20 in the lower compartments and we will make use of neutron radiography to trace the transport of D_2O through the root systems of trees and crops. D_2O will be injected at varying soil moisture conditions, to determine at what conditions hydraulic lift occurs. We will quantify the distribution of D2O in soil and roots according to Zarebanadkouki et al. (2012). We will use the model of Zarebanadkouki et al. (2014) to quantify the water fluxes out of the roots and into the roots. These laboratory experiments will provide important information on the mechanism of hydraulic lift. We will test whether direct contact between roots is needed for the water exchange between plants. This information will be useful to interpret the field experiments.

To interpret the experimental observations of soil water content, soil and plant water potentials and transpiration, we will employ the physical based soil water model described in TP8, in which the water flow in soil and roots is explicitly calculated. The model will be first tested for the Reiffenhausen site and will be then applied to all sites. For this we will use the soil water measurements of the core design. The model will help to predict future scenarios and design optimal distances between tree lines depending on atmospheric conditions, soil properties and root properties (i.e. root depth and root length distribution).

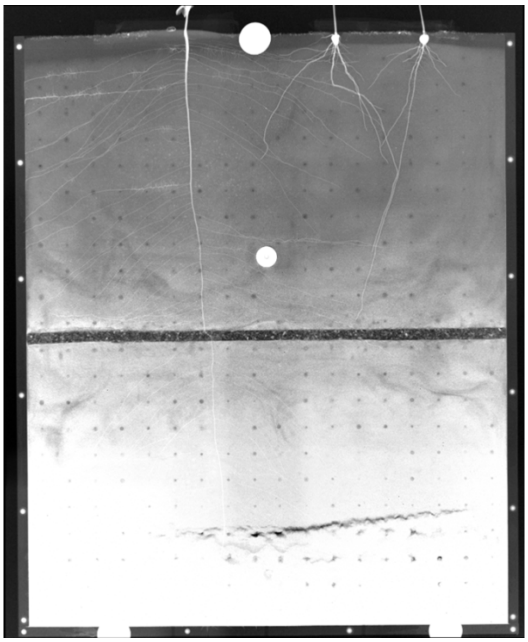

Fig. 5*: Neutron radiography of three plants growing in a sandy soil. The plants were a 2-months old lupines (left) and two-weeks old maizes (right) that had roots only in the upper half of the soil. A layer of coarse sand hydraulically disconnected the upper and lower parts of the soil. The image shows the water content in soil and plants (white=wet). A similar set-up will be used to test the hydraulic lift experiment. Heavy water will be injected in the lower part of the sample and its transport through the deep-rooted plants and eventually to the maize roots will be monitored over time by means of neutron radiography. The size of the sample was 60 cm x 50 cm x 1 cm.*

Verwertungsplan

Synchron zum TP3-1 liefert das TP3-2 Erkenntnisse zum Wasserhaushalt der Rhizosphäre im Interaktionsbereich von Acker und Baumstreifen. Neben einem erweiterten Verständnis zu spezifischen Prozessen (z.B. Hydraulischer Lift, Wirkung von Mucilage/Schleim als Wasserspeicher) wird das Teilprojekt insbesondere Antworten auf Fragen zur möglichen Konkurrenz um Wasser in Agroforstsystemen liefern. Über gesonderte Modellanwendungen können auch hier Aussagen z.B. über mögliche Trockenstressrisiken oder gegenseitige Bevorteilungen durch z.B. die Erschließung zusätzlicher Vorräte abgeleitet werden.

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TP3-2 (Carminati & Jansen)	Soil hydrology and rhizosphere processes in agroforestry systems											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student, student assistance for field installations) (**M**)												
Purchase of equipment for soil chemical and soil physical (e.g. TDR; Data logger, GPRS) field station Reiffenhausen (**M**)												
Installation and calibration of the instruments in the field (site Reiffenhausen) and first set of measurements (**M**)												
Soil hydrological properties analysed and data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre (**D**)												
Fieldwork and measurements of soil hydrology (**M**) and data transfer to modelling TP (7, 8) and to data base of BonaRes-Centre (**D**)												
Experiment in the lab/field on hydraulic lift with heavy water (**M**)												
Modelled water fluxes of AF-system Reiffenhausen available for other working groups (**D**)												
Identification of the most important parameters needed to understand the plant and soil hydrology in agroforestry systems, communicated to stakeholders (**D**)												
Annual project meeting (**M**) and annual / final reports (**D**)												
Manuscripts on (1) plant/soil interaction in AF-systems and (2) modelling of hydro-logical interaction written and submitted (**D**)												

TP4-1 Grassland tissue and litter production as affected by tree x grass sward interaction and grassland management

Principal Investigators: J. Isselstein[1], M. Kayser[1], B. Tonn[1]

[1] University of Göttingen, Department of Crop Sciences, Grassland Science

Scientific background and current status of research; previous work

In grassland systems a broad range of processes control the retention and turnover of matter and nutrients leading to a spatial and temporal segregation of matter and nutrients stocks. Nutrient use efficiency and nutrient losses from the plant-soil system are directly affected (Whitehead 1995). Inclusion of trees in silvo-pastoral systems further modifies the nutrient turnover (Abraham et al., 2014, Peri et al. 2007). Immediate sources for C and N in grasslands are excreta of grazing animals, microbial biomass and plant litter, i.e. the herbage that remains unused and contributes to the soil organic matter via senescence and decomposition. Litter makes up 50% or more of the total herbage production, even in intensively managed grasslands (Parsons et al. 1983). Depending on the C/N ratio of the plant tissue, N is either mobilized or immobilized and thereby the nutrient availability for the growing grass sward is affected (Sanaullah et al. 2010). The amount of litter is controlled by a range of factors such as the frequency and type of defoliation and the availability of nutrients, water and light. In addition, litter formation in a leafy canopy is closely related to the phyllochron and the leaf life span (McMaster 2005, Hikosaka 2005, Schleip et al. 2013). Competition among trees and the herbaceous vegetation affects the growth of both components of a silvo-pastoral system. So far, no information is available on the effects of tree cover on the tissue turnover of a grass sward and the organic carbon and nitrogen in the litter that feed decomposition processes and carbon stocks in the soils. The objective of this TP is to study the combined effects of tree/grass sward competition and grassland management on the herbage growth and the canopy tissue turnover.

Preliminary work and previous achievements of the applicants

The grassland group of Göttingen University focuses on the management and related nutrient and tissue turnover of agricultural grasslands. Latest research activities are concerned with effects of management and sward composition on agronomic productivity and environment. The interaction of biodiversity and productivity, also under conditions of climate change, has been studied in several national and international joint projects. This line of research is complemented by a long-standing analysis of nutrient cycling and emission risks of forage farming systems and land use changes. We see great potential in working interdisciplinary and across a range of scales from the single plant, the functional group and sward to the field, farm and even landscape scale.

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Sahin Demirbag, N., Röver, K.U., Wrage, N., Hofmann, M., Isselstein, J., 2009. Herbage growth rates on heterogeneous swards as influenced by sward-height classes. Grass and Forage Science 64, 12-18.

Detailed description of the work plan

We plan to describe effects of agroforestry on yield development of the grass part at all sites of the core design that contain grassland, i.e. Reiffenhausen and Mariensee. Our aim is to find out about processes that determine the sward development and productivity of grassland in agroforestry systems. At both sites we will apply a double-sampling method using the rising plate meter technique to study matter production and turnover (Correll et al. 2003, Sahin Demirbag et al. 2009). Measurements will be done in established plots and in transects leading from tree rows into the grass strips. In Reiffenhausen there will be additional factors varied, i.e. the grassland mixture and the cutting intensity (Tab. 3). There we will focus on leaf development and senescence and how they depend on environmental factors, leaf life span and sward composition. To do so we need to consider three scales of observations from the single plant to the species and sward scale. Field measurements will be done over two growing seasons. Research activities of TP4-1 will be conducted in close collaboration with TP2-2 in the silvo-pastoral agroforestry system in Reiffenhausen, combining grassland and willows in an alley cropping design and with TP5 in the silvo-pastoral system of Mariensee.

Table 3: Experimental design: level 1: main plots according to TP2-2 (factor 1 and 2), level 2: sub-plot level, and, level 3: individuals from three functional groups, Reiffenhausen

Level 1: factor 1 and 2 Level 2: factor 1, 2 and 3		
Factor 1 grassland mixture	Factor 2 cutting intensity	Factor 3 distance from trees
• grass clover mixture • diverse mixture	• 2 cut per year • 4 cuts per year	• near • at a distance
Level 3: individual plants		
• grass	• legume	• forb

1. Sward level measurements

According to our approach of different scales, we will differentiate our experimental design into three levels. Level 1 is formed by the existing field experiment in Reiffenhausen and Mariensee and managed and sampled by TP2-2 and TP5. In Reiffenhausen we will work on level 2 and 3: level 2 consists of sub-plots that are integrated into the field experiment with an added factor, distance to the tree line. At the sub-plot level we will determine, in addition to the superimposed management scheme of level 1, every 2 weeks (4 weeks after July): yield, functional groups (grass, legume, forb) and tiller (stolon, plant growing point) density, sward height (rising plate meter); harvested material will be separated into live and dead tissue (>75% chlorotic leaf area) and analysed for C and N. This assessment of the quality of senescent and dead plant material offers a direct link to C and N processes in the soil. Parameters like tiller (stolon, plant) density and functional group will form a link to upscale findings from the single plant scale to the sward scale and finally field scale.

2. Single plant level measurements at Reiffenhausen

In a grass sward, leaf tissue turnover and litter formation is closely related to the morphology and the physiology of the grassland plant. Therefore, in all treatments at the sub-plot level, four single plants of all functional groups (i.e. grass, legume, forb) will be marked at the beginning of the season and the leaf life span of emerging leaves will be quantified in relation to the thermal time until the end of the season. In 2-

weekly intervals distinct morphological traits like leaf appearance rate (LAR), leaf senescence rate (LSR), number of live leaves (NLL) and leave life span (LLS) will be determined (Calviere & Duru 1995). According to Schleip et al. (2013) leaf birth is defined as the stage where the tip of a leaf emerges from the sheath of the next older leaf. A leaf is live until <25% of the tissue is senescent. Leaf size, leaf water content and specific leaf area will be measured on the youngest fully developed leaf per plant (Cornelissen et al. 2003). The leaf nitrogen content will be measured which in combination with the total aboveground nitrogen content gives an indication of the nutritional status of the plants (Gastal & Lemaire 2002). The isotopic composition of the leaf nitrogen ($^{14}N/^{15}N$) will be determined to give an indication on the source of nitrogen (soil, nitrogen fixation by legumes).

3. Environmental effects

Regular measurements of soil mineral N (0-30cm), water content, photosynthetic active solar radiation (FiPAR method, ceptometer) and air and soil temperature (automated meteorological measurements) at the sub-plot level allow for a description of the environmental effects of agroforestry systems on leaf development in single plants and the resulting sward by correlation/regression analyses.

Verwertungsplan

Die Arbeiten von TP4-1 liefern Ergebnisse zu den Grundlagen von Ertragsleistung und Qualitätsaspekten von Grasland in Agroforstsystemen. Zu wissen, wie der Ertrag in diesen Systemen aufgebaut wird und von welchen Prozessen er abhängt, ist unerlässlich für die langfristige Steuerung und Nutzung von Agroforstsystemen. Dabei kommt der Betrachtung der spezifischen Umwelteinflüsse auf die Entwicklung der Einzelpflanze und der artlichen und funktionalen Zusammensetzung eine besondere Bedeutung zu. Damit ergänzen die Arbeiten von TP4-1 in idealer Weise die Untersuchungen von TP2-1 und TP5 und stellen über die Betrachtung von Blattaufbau und Verlusten durch Seneszenz eine direkte Verbindung zum N- und C-Kreislauf zwischen Pflanze und Boden her.

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TP4-1 (Isselstein, Kayser, Tonn)	Grassland production and management											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student and student assistance for field installations) **(M)**												
Set-up of pot experiment **(M)**												
Establishing field experiment **(M)**												
Start of sampling field experiments (LAR, LSR, LLS, LAI, yields, N, C in harvested biomass, 2 vegetation periods) **(M)**												
Delivery of results of field experiments (sward composition, species, distance trees, management, single plants), data transfer to data base of BonaRes-Centre **(D)**												
Annual project meeting **(M)** and annual / final reports **(D)**												
Manuscripts on leaf appearance and senescence, (1) pot experiments: species, N, water, shading; (2) field experiments: sward composition, distance to trees, management, written and submitted **(D)**												

TP4-2 Socio-economic evaluation of agroforestry systems

Principal Investigator: Prof. Dr. Ludwig Theuvsen[1]

[1] University of Göttingen, Department of Agricultural Economics and Rural Development

Scientific background and current status of research; previous work

Socio-economic evaluations consider the social and economic effects that economic activities, i.e. in this case: grassland agroforestry, cropland agroforestry and conventional agricultural production systems, have on society or on specific stakeholders (Mikl-Horke 2011; Henke and Theuvsen 2014). Due to their low relevance so far, there are only few economic evaluations of agroforestry systems which take into account the specific legal, natural and societal conditions in Germany. One exception is the paper by Emmann et al. (2013b) who analyse the economic (dis-)advantages of alley-cropping systems in the German state of Brandenburg. By varying production cycles, tree species, distances between alleys, harvesting technologies and prices, the authors determine necessary subsidies to motivate farmers to implement alley-cropping systems. Kröber et al. (2010) and Wolbert-Haverkamp (2012) analyse the economic sustainability and risk profile of short rotation coppices. Wolbert-Haverkamp's (2012) Monte-Carlo simulation showed that short rotation coppices are only preferable under very specific conditions. More recently, Wolbert-Haverkamp and Mußhoff (2014) used the real-option approach to analyse why farmers are reluctant to change land use to short rotation coppices despite obvious ecological advantages and financial incentives offered in several countries. Wolbert-Haverkamp et al. (2014) added a value chain approach by also taking into account the pricing behaviour of biomass heating stations and its effect on farmers' choice to change to short rotation coppices. All in all, only preliminary and – with regard to natural conditions, alternative crops, and structural characteristics of agriculture – not very detailed insights into the economic effects of the implementation of agroforestry systems are currently available.

Modern agricultural economic research increasingly acknowledges that not only farmers' assessment of the economic sustainability of land use systems but also farmers' and other stakeholders' (for instance, lessors') attitudes towards alternative agricultural production systems are important determinants. Emmann et al. (2013a) used structural equation modelling for analysing farmers' acceptance of the biogas innovation, i.e. farmers' willingness to devote arable land to the production of energy maize and other substrates. The need for a broader view taking also emotional, social and attitudinal effects into account was also shown by research into farmers' acceptance of, for instance, quality management systems (Jahn and Spiller 2005), use of information provided by external sources (Arens et al. 2012) or new technologies, for instance slurry separation (Kröger and Theuvsen 2014). Similar results could be obtained with regard to other stakeholders' acceptance of renewable energy production (Henke 2014). With regard to agroforestry systems, this perspective has not been applied so far although prior research has already addressed the need for a broader perspective which also considers other determinants than gross margins and risk and other stakeholders than farmers (Wolbert-Haverkamp 2014).

Modern agriculture and food production are increasingly exposed to the public eye (Jansen and Vellema 2004). Recent research has revealed dramatic image deficits of agriculture and decreasing societal support for various agricultural production technologies (Kayser 2012). Against this background, it is widely accepted that more research into the relations of agriculture to society is needed (Grunert et al. 2005). Whereas genetically modified organisms, animal welfare and other highly socially debated topics have frequently been analysed, alternative land use systems have only gained very limited attention. So far there is hardly any knowledge on the preferences of the wider public in developed countries for agroforestry systems although these preferences might be decisive for the willingness to financially support these ecologically more sustainable production systems.

Against this background, this research has the following <u>objectives</u>:

(1) Analyse the economic effects of the implementation of agroforestry systems at the farm level in consideration of relevant contingency factors such as natural conditions, alternative crops, and structural characteristics of agriculture in the regions under analysis;

(2) empirically analyse farmers' and other important stakeholders' (for instance, lessors') acceptance of more sustainable land use systems such as agroforestry;

(3) analyse the valuation of alternative land use systems by the wider public.

Preliminary work and previous achievements of the applicants

Professor Theuvsen has done extensive research on economic aspects of various agricultural production systems such as dairy production (Bronsema et al. 2014), pork production (Spiller et al. 2005), slurry separation (Kröger and Theuvsen 2013) or production of renewable energies (Emmann et al. 2013b). Furthermore, he has broad experience with the application of structural equation modelling for analyzing farmers' and other stakeholders' acceptance of alternative production technologies (Heyder et al. 2012; Arens et al. 2012; Emmann et al. 2013a). Recent research has addressed bioenergy production (Emmann et al. 2013b), agroforestry systems (Emmann et al. 2013c) and other more sustainable land use alternatives (e.g., Guenther-Lübbers et al. 2012). Much of Professor Theuvsen's research has addressed societal issues such as acceptance of renewable energy production or intensive livestock farming by the wider public (Zschache et al. 2012; Heise et al. 2014) and society's expectations regarding modern agriculture and food production (Heyder and Theuvsen 2009). Adaptive conjoint analysis was used to address consumers' preferences for alternative characteristics of food production systems such as transparency (Arens et al. 2011). Recent studies have addressed socio-economic aspects of agricultural production systems (Henke and Theuvsen 2014a). This research resulted in the development of an advanced version of the Social Life Cycle Assessment methodology (Henke and Theuvsen 2014b).

5 most important references:

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Detailed description of the work plan

The economic analysis of the effects of the implementation of cropland and grassland agroforestry systems at the farm level is based on calculations of net present values of alternative land use systems. Unlike the vast majority of prior research, we take into account detailed information on natural conditions, alternative crops, and structural characteristics of agriculture in the regions under analysis. The economic analysis is based on secondary data, publicly available standard values, and additional data collected through on-farm visits and expert interviews.

Empirical data on farmers' and other stakeholders' attitudes towards alternative agricultural production systems is collected through a questionnaire-based large-scale empirical study. Farmers and other respondents will be addressed in the regions where the experiments will be conducted (Dornburg, Forst, Wendhausen, Reiffenhausen, Mariensee) to take into account local natural and societal conditions as well as varying preferences and attitudes. Farmers and other stakeholder will be addressed through a random sampling strategy in collaboration with local farmer, civil society and public organizations. The questionnaire will be based on psychological literature on the cognitive, emotional and intentional aspects of farmers' and other stakeholders' (such as agricultural service providers, the local populace (neighbours), competitors for production factors and the wider society) attitudes towards agroforestry systems. Data from at least 200 farmers and 200 other stakeholders will provide the basis for uni-, bi- and multivariate analyses with SPSS Statistics and, where possible, additional analyses through structural equation modelling with SmartPLS.

The societal valuation of agroforestry systems uses choice-based conjoint analysis for analysing the preferences of citizens (consumers) regarding alternative agricultural production systems. This analysis will focus on those elements of agroforestry systems which laypersons, i.e. consumers, can easily distinguish from conventional land use (such as the appearance and diversification of the landscape) and which they may appreciate (or dislike). Consumers will be surveyed online; the online survey will be designed with the software ACA 8.2 from Sawtooth Software. Participants will be recruited with the help of a private panel provider.

Verwertungsplan

Das TP4-2 liefert kurzfristig bessere Information an die Landwirtschaft und deren Stakeholder über die ökonomischen Effekte von Agroforstsystemen unter verschiedenen situativen Bedingungen. Mittelfristig steht – u.a. auf der Grundlage vertiefter Erkenntnisse über die Einstellungen von Landwirten und diversen Stakeholdern sowie die Wertschätzung nachhaltigerer Landnutzungssysteme durch die Bevölkerung – die Entwicklung von Programmen zur Förderung der Umstellung auf Agroforstsysteme im Vordergrund der Projektaktivitäten. Langfristig zielen die Arbeiten auf die intensivere Berücksichtigung und Förderung von Agroforstsystemen in der nächsten Reform der Gemeinsamen Agrarpolitik (GAP). Dabei gelangen alle wissenschaftlichen Ergebnisse laufend über Multiplikatoren (Berater etc.) und durch fachspezifische, aber auch praxisnahe Publikationen und Vorträge in die landwirtschaftliche Praxis.

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TP4-2 (Theuvsen)	Socio-economic evaluation of agroforestry systems											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student, student assistant) (M)												
Literature review on agroforestry systems completed (M)												
Collection of available secondary data and standard values and of data through on-farm visits and expert interviews completed (M)												
Calculation of net present values of alternative agricultural production systems (M) and report on economic effects completed (D)												
Design of questionnaires on attitudes completed (M)												
Collection and analysis of survey data (M) and report (D) completed												
Preparation of choice-based conjoint analysis completed (M)												
Design of questionnaires, collection and analysis of survey data completed (D)												
Data collection on societal valuation completed (M) and reported (D)												
Annual project meeting (M) and annual / final reports (D)												
Manuscripts on (1) economic effects of agroforestry systems, (2) farmers' and other stakeholders' attitudes, (3) societal valuation of agroforestry systems submitted (D)												

TP5 Quality of in- and outputs of crop and tree biomass in agroforestry systems

Principal Investigators: J. M. Greef[1], M. Langhof[1], K.U. Schwarz[1]

[1] Julius Kühn-Institut, Braunschweig

Scientific background and current status of research; previous work

Soil is a living and dynamic ecosystem, that can be disturbed by agricultural actions. One considerable disturbance is the continuous removal of biomass with crop harvest that is essential for the formation of soil organic matter (SOM, i.e. any plant- or animal-based material that is decomposed in the soil). As SOM possesses many essential soil functions, such as nutrient provision to plants and soil organisms or improvement of aggregate stability and water-holding capacity, its permanent loss from the soil is a main cause for soil degradation. A key to sustainable increase of both soil fertility and soil functionality is the maintenance or even enhancement of the SOM content in the soil. In addition to several management methods (e.g. cover crops) this can be achieved by innovative and sustainable agricultural systems. Through agroforestry systems perennial plants are permanently integrated into the agroecosystem. In consequence, additional SOM sources (leaf and wood litter, root exudates) are added to the agroecosystem (Pinho et al., 2012; Tsonkova et al., 2012). As recently reviewed for SRC (short rotation coppice) strips on cropland (Tsonkova et al., 2012) and for SRC plantations (Dimitriou et al., 2011; McKay, 2011), SRC can enhance both the soil organic carbon and N content. The deeper rooting system of trees compared to most crops allows for nutrient uptake from deeper soil layers that cannot be reached by crop plants (Nerlich et al., 2012) and reduces nutrient losses to seepage and groundwater (Böhm et al., 2013); nutrients are circulated ("nutrient pump") and returned to the top soil with litterfall (Allen et al., 2004; Zamora et al., 2009). Thus, spatial differences in the SOM contents between perennial tree strips and annual crop strips are expected over a longer period. For example, several authors (e.g. Mungai et al., 2006; Nii-Annang et al., 2009; Tsonkova et al., 2012) report higher soil organic carbon and nitrogen contents within older (i.e. > 9 years) tree strips compared to the centre of the adjacent crop strips. Moreover, poplars and willows in agroforestry strips have the potential to intercept mineral nutrients leached from the adjacent crop root zone by rooting below the crop root zone ("safety net function"). Thus, nutrients are bound in the SOM so that they are not endangered of leaching. Due to N-fixation in poplar and willow (Doty et al., 2005), reduced fertilizer usage in SRC results in a decrease of surplus nutrients in the soil and can also prevent nutrient leaching to the ground water (von Wühlisch, 2011).

With the introduction of perennial tree strips to cropland transition zones between perennial and annual cultures arise. These transition zones are characterized by an altered microclimate, competition for resources (water, light, nutrients, space) between trees and crops and further impacts (e.g. tree litter on seedlings). Growth characteristics, quality and yield of annual crops in the transition zone might differ from those in the middle of the crop strip (Lamerre et al., 2014), where effects of the tree strips are weaker or not existent.

Objectives: Our objective is to evaluate, over a long period of time, whether the tree-specific inputs (organic matter and nutrients through leaf, wood and root litter) as well as tree-specific characteristics (e.g. rooting in deeper soil layers) contribute to a sustainable and permanent increase in soil fertility in agroforestry systems. Since the build-up of soil fertility is a long-term process, data are collected from already established agroforestry sites (>7 years old). A spatial analysis of in- and outputs of above-ground biomass will be conducted.

Preliminary work and previous achievements of the applicants

In the frame of the research project AgroForstEnergie I and II (funded by FNR from 02/2008 to 03/2015) the Julius Kühn-Institute for Crop and Soil Science studied the combined production of woody biomass and agricultural crops within agroforestry systems and evaluated this form of production both economically and ecologically. A main aspect of this study was to test whether the profitability of the whole agroforestry system is positively and sustainably influenced by the interaction of trees with agricultural crops. The Institute for Crop and Soil Science established two alley-cropping systems in 2008, one at the site Wendhausen and one at Mariensee. At the Wendhausen site the system combines the production of fast-growing poplars with the cultivation of annual field crops on a site that was formerly used only for agriculture. In this alley-cropping system 12 m wide poplar strips are alternating with 48 and 96 m wide crop strips. At the Mariensee site 10 m wide willow strips are alternating with 48 m wide grassland strips.

Results of the research project AgroForstEnergie indicated that yields of annual crops can be below the field average yield in the vicinity to tree strips (approximately up to 5 m into the field) but increase with distance into the field to reach a maximum approximately at the field center. However, this effect could not be shown in every year and not for every crop species tested. Lower yields in the transition zone were explained by the altered abiotic (e.g. lower wind speed, higher air temperature, higher relative humidity) as well as biotic factors (e.g. higher aphid density, soil covered by tree litter) in this zone between crop and tree strips. Depending on the position within strips (i.e. leeward, windward or middle row) growth conditions for trees within strips differ. Higher light and space availability as well as wind sheltering can positively influence poplar growth; thus, biomass production was highest in the leeward rows.

5 most important references:

Lamerre J, Schwarz KU, Langhof M, von Wühlisch G, Greef JM. 2015. Productivity of Poplar Short Rotation Coppice in an Alley-Cropping Agroforestry System. Agroforestry Systems (accepted).

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Lamerre J, Schwarz KU, Langhof M, Bliefernich S, Greef JM. 2013. Strukturelle Vielfalt eines agroforstwirtschaftlichen „Alley-Cropping“ Systems als Chance für die Nachhaltigkeit. Mitteilungen der Gesellschaft für Pflanzenbauwissenschaften 25:110-11.

Schwarz KU, Langhof M, Greef JM. 2011. „AgroForstEnergie“: Energieholz und Strukturvielfalt. Forschungsreport 1:44-45.

Detailed description of the work plan

Work conducted within TP5 concentrates on three main subtasks, i.e. amounts and qualities of above ground biomass inputs (1) as well as outputs (2) of annual crops and perennial trees as well as detailed spatial yield analyses (3) of both crops and trees. Methods employed will be identical to those conducted at Dornburg (TP6), Forst and Lausitz (TP7) as well as Reiffenhausen (TP2). TP5 centrally analyses quality parameters of biomass samples from the core design plots at Wendhausen, Mariensee (TP5) and Dornburg (TP6). In addition, TP5 will provide logistical support for research activities of other SIGNAL TPs at the Wendhausen and Mariensee alley cropping sites.

(1) Amounts and qualities of above ground biomass inputs:

Background: The amount and quality of organic matter that is returned to the soil with tree (litter) and crop residues and the resulting effects on soil fertility and nutrient cycling are evaluated.

Perennial trees: At the core plots in Wendhausen and Mariensee, during the whole period of litterfall the total amount of litter per square meter will be assessed using 1 m x 1 m litterfall traps. To analyse the spatial distribution of tree litter, traps will be placed along transects into the crop field as well as directly within the tree strip. Litterfall will be measured at 1, 3, and 7 m (according to positions of soil moisture measurements) as well as at 12 and 24 m from the tree strips within the core design plots with 4 replicates. The spatial distribution of litter will be analysed and extrapolated to plot level using GIS. Litter quality will be assessed through the determination of nutrient (C, N, P, K, Ca, Mg, S) concentrations, lignin content as well as cellulose content.

To determine decomposition rates of litter in the top soil, litterbags containing air-dried litter samples are placed on the soil surface in the shaded and unshaded zone of the crop field. Temporal changes of nutrients bound in the litter will be determined. Data will refer to the activity and diversity of the soil organism communities evaluated by TP2-1. These analyses will also be conducted at the Dornburg site (TP6).

Annual crops: At the Wendhausen site quantity and quality of harvest residues of annual crops will be estimated. Quantity is determined by weighing and quality will be assessed through the determination of nutrient (C, N, P, K, Ca, Mg, S) concentrations in samples taken at 1, 3, and 7, 12 and 24 m from the tree strips within the core plots. In addition, litterbags containing air-dried harvest residues are placed on the soil surface in the shaded and unshaded zone of the crop field. Also here, temporal changes in the decomposition rate as well as changes of nutrients bound in the residues will be determined (see above).

All nutrient analyses will be conducted in the equipped and experienced laboratory of the Julius Kühn-Institute of Plant and Soil Science using approved methodologies (i.e. ICP (Inductively Coupled Plasma) analysis; C, N-analysis according to Dumas). Qualified staff is available. Lignin and cellulose contents of selected samples of tree litter will be analysed by the Thünen Institute of Wood Research.

(2) Amounts and qualities of above ground biomass outputs:

Background: The amount and quality of organic matter that is regularly removed from a site by biomass (annual crops, grassland and perennial trees) harvesting and the resulting effect on soil fertility is analysed.

Perennial trees: At the Wendhausen and Mariensee sites, we plan to estimate tree growth in the core plots by measuring diameter increment at breast height (1.30 m) and tree height. Moreover, in each year above ground tree biomass is destructively sampled by harvesting trees from different positions within tree strips (edge row leeward, middle row, edge row windward). Data on diameter at breast height and dry mass allow for the estimation of annual tree biomass production according to Verwijst & Telenius (1999). To quantify growth characteristics of trees in dependence on the position within the strip, age, number of rotation cycles etc. as well as value for bioenergy use, we will distinguish four components of trees: bark, branch, wood, and foliage. Fresh weights are determined in the field and dry weights are assessed based on samples of each component in the laboratory. Ratios of components of trees from different positions within tree strips are compared and analysed qualitatively through the determination of nutrient (C, N, P, K, Ca, Mg, S) concentrations. In order to not disturb other investigations, destructive sampling is not conducted within the core design plots but in the immediate vicinity as well as in the SRC reference.

At Wendhausen trees are harvested with a 3- and 6-year rotation cycle, respectively. Trees with a 3-year cycle will be harvested again in January/February 2017, those with a 3 and 6-year harvest cycle in 2020. While harvesting, trees from different positions within tree strips will be weighed to compare tree growth within the strips (i.e. leeward, vs. windward, vs. middle) as well as against the SRC reference. Next harvest at the Mariensee site will take place in January/February 2021.

Annual crops: The nutrient removal with the harvest of the crops is estimated through the determination of nutrient (C, N, P, K, Ca, Mg, S) concentrations in crop samples from the core design plots. Further quality parameters to be tested are: grain yield (weighing), straw yield (weighing), dry matter content grain (weighing, drying at 105°C, re-weighing), dry matter content straw (weighing, drying at 105°C, re-weighing), grain/straw ratio (calculation), thousand seed weight (weighing), hectolitre weight (according to Egger, 1989; using a grain tester model KERN 220/222), Besatz (i.e. all components of a grain sample that differ from the normal basic cereal; sieving and manual selection). With NIRS (near-infrared spectroscopy) the protein, starch as well as water contents are determined for cereal grains and the oil, protein as well as glucosinolate contents are determined for oilseed rape seeds using the approved methods described by Ohnmacht & Hahn, 2011. The amount of biomass output with crop harvest is quantified during harvest (see below). Nutrient analyses from samples taken at 1, 3, and 7, 12 and 24 m from the tree strips will be conducted in the laboratory of the Julius Kühn-Institute of Plant and Soil Science, as described above. NIRS analyses will be conducted in the equipped (Zeiss and Polytec spectrometers) and experienced laboratory of the Julius Kühn-Institute of Plant and Soil Science using established calibrations (Ohnmacht & Hahn, 2011). Qualified staff is available. In addition to the samples from the core design plots at the Wendhausen site, TP5 centrally analyses nutrient concentrations as well as protein, starch, water contents (cereals) and oil, protein and glucosinolate contents (oilseed rape) for samples from the core design plots at the Dornburg site (TP6).

Grassland: The nutrient removal with grassland cuts at the Mariensee site is estimated through the determination of nutrient (C, N, P, K, Ca, Mg, S) concentrations in harvested samples. Grassland will be cut 4 times a year at boot stage. The amount of biomass output with each cut will be quantified by calculating the dry matter yield per square meter from samples collected at 50 x 50 cm squares at 1, 3, 7, 12 and 24 m with 4 replications each within the base design plots. These activities will be conducted in cooperation with TP4-1.

(3) Spatial yield analyses of crops and trees:

Background: With the introduction of perennial tree strips on cropland transition zones between perennial and annual cultures are created. These transition zones are characterized by an altered microclimate, competition for resources (water, light, nutrients, space) between trees and crops and further impacts (e.g. tree litter on seedlings). Growth characteristics, quality and yield of annual crops are altered in the transition zone. At greater distance effects of tree strips might have a positive effect on crop growth. Within tree strips biomass production as well as growth parameters (e.g. number of branches, tree height) of trees is expected to differ depending on row position (outward vs. middle).

Perennial trees: At the Wendhausen and Mariensee site the productivity of the different tree rows (i.e. leeward edge row, middle row, windward edge row) is estimated yearly as described above (2, according to Verwijst & Telenius (1999)) as well as measured during tree harvests conducted in a 3 or 6-years interval (methods described above, 2)). Data are interpreted with regard to optimization of biomass production and will be delivered to TP7 (biomass modelling) and TP8 (modelling of agroforestry systems).

Annual crops: At the Wendhausen site annual crop yield estimation and mapping will be done with a GPS-equipped harvester on all crop fields of the agroforestry site as well as the reference fields. The spatial distribution of yields in dependence of the distance from the tree strips is analysed and contoured using GIS. Moreover, yield components (e.g. seed weight, number of florets, number of seeds, grain/straw ratio, protein content, etc. (cereals); number of pods per plant, number of seeds per pod, number of plants per m², seed weight, etc. (oilseed rape)) of the crops are determined at 1, 3, 7, 12 and 24 m from the tree strips with 4 replicates each within the core design plots. The same analyses are conducted at 1, 3, 7, 12 and 24 m from the field edge in the reference fields, also with 4 replicates.

Grassland: At the Mariensee site developmental stages (BBCH) and yield components of grassland (e.g. shoots per m², numbers of internodes, dry matter, etc.) are determined at 1, 3, 7, 12 and 24 m from the tree strips with 4 replicates each within the core design plots shortly before each cut. The same analyses are conducted at 1, 3, 7, 12 and 24 m from the field edge within the grassland reference also with 4 replicates. These data are completed by the analyses of biomass output (see above (2)) and will be conducted using similar methods conducted by TP2-2 at the silvopastoral system in Reiffenhausen.

Verwertungsplan

TP5 stellt für den Projektverbund wesentliche Versuchsflächen bereit und betreut sie. Dabei liegt der Schwerpunkt der eigenen wissenschaftlichen Arbeiten auf der Ableitung von Handlungsempfehlungen zur Steigerung der Ertragsleistungen. Diese beruhen auf der laufenden Erfassung und Analyse von Zuwächsen (Holz) und Ackererträgen, der Streuproduktion sowie der Analyse der jeweiligen Nährstoffgehalte und -umsätze. Die Ergebnisse werden in enger Kooperation mit den inhaltlich unmittelbar benachbarten TPs (TP4, TP6) so aufgearbeitet, dass sie i) vergleichend zwischen den beteiligten TP ausgewertet und ii) direkt zur Modellierung im TP7 (Yield SAFE) und TP8 (Expert-N) genutzt werden können. Gleichzeitig liefert TP5 einen direkten Dateninput in das BonaRes Zentrum. Ein besonderer Fokus von TP5 liegt in der Verbesserung der Bewirtschaftung von marginalen sowie Problemstandorten (Bodenverdichtung, Erosionsgefahr, etc.) mittels agroforstlicher Anwendungen. Insgesamt sollen Ansätze erarbeitet und weiterentwickelt werden, wie mittels der agroforstlichen Maßnahmen eine nachhaltige und sowohl ökonomisch als auch ökologisch signifikante Aufwertung der Standorte erreicht werden kann. Es wird erwartet, dass sich im Verlauf der ersten Projektphase weitere Fragestellungen, etwa zur praktischen Umsetzung bzw. Optimierung von Agroforstsystemen, ergeben. Diese werden in der zweiten und dritten Projektphase von SIGNAL aufgegriffen und experimentell bearbeitet.

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TP5 (Greef, Langhof & Schwarz)	Quality of crop and tree biomass in agroforestry systems											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student and student assistance for field installations) **(M)**												
Start of continuous tree litter sampling as well as estimation of decomposition rates of litter in the top soil using litterbags and analysis (**M**), data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Start of continuous collection of crop and grassland samples for quality analysis (**M**), incl. data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Nutrient and quality analyzes of crop, litter and wood samples from Wendhausen (TP5) and Dornburg (TP6) (**M**) incl. data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Data supply of distribution, quantity, decomposition rate and quality for organic matter that is returned to the soil **(D)**												
Start of annual tree diameter, tree height and above ground biomass measurements **(M)**												
Harvest of tree strips in 3-year rotation cycle for poplars at Wendhausen **(M)**												
Annual project meeting **(M)** and annual / final reports **(D)**												
Manuscript on (1) quality, amount and distribution of tree litter input and its decomposition rates and (2) quality and amount of biomass (annual crops and perennial trees) in- and outputs written and submitted **(D)**												

TP6 In- and outputs of above-ground biomass, site management Dornburg, linking science and practice

Principal Investigators: T. Graf, M. Bärwolff, A. Vetter[1]

[1] Thuringian State Institute for Agriculture (TLL)

Scientific background and current status of research; previous work

Previous research on the topic of modern agroforestry systems stated possible advantages and characteristics coming along with this special form of agriculture, for example that biomass productivity and profitability can be higher in agroforestry than in forestry or agricultural monocultures (Cannell et al. 1996, Kho 2008, Jose et al. 2012, Tsonkova et al. 2012) and that agroforestry can be more sustainable than forestry or agricultural monocultures (Sanchez 1995, Oelbermann et al. 2004, Alavalapati 2004, Eichhorn et al. 2006).

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 (BMU & BMELV 2009). So far, the cultivation of fast growing trees on German agricultural area is implemented only hesitantly by German farmers. In 2014 nationwide about 9000 hectares of agricultural land were cultivated with plants for solid fuel (mainly energy wood and miscanthus) (FNR 2014).

Despite all positive predictions German and European farmers shy away from establishing agroforestry systems. Several reasons can be mentioned, beginning with high establishment costs (Nerlich et al. 2013), hindering legal frameworks (Chalmin 2008), lack of financial incentives (Smith et al. 2012), and not least lack of information (Graves et al. 2009) and positive examples (Christen & Dalgaard 2012, Böhmer & Wagener 2013).

Objectives:

(1) To evaluate the potential for a sustainable increase of soil fertility connected with tree-specific characteristics (rooting in deeper soil layers) and inputs (organic matter and nutrients through leaf, wood and root litter) to the agricultural system.

(2) To provide logistic support and additional data required by other TPs.

(3) To link agroforestry science and agricultural practice by enhancing the mutual information flow of latest research findings and practical requirements.

Preliminary work and previous achievements of the applicants

The Thuringian State Institute for Agriculture coordinates the joint research project AgroForstEnergie I and II (funded by the German Federal Ministry of Food, Agriculture and Consumer Protection 07/2007 – 03/2015). AgroForstEnergie aims to link sustainability and productivity in agriculture with positive effects for environment and farmer. It was initialised to look at alley-cropping systems which combine the production of woody biomass with conventional field crops. 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 to increase the biodiversity in the agrarian landscape.

The Thuringian State Institute for Agriculture established in 2007 a large scale alley cropping system (50 ha) in a structurally poor and intensively agriculturally used area of Thuringia. Seven poplar short rotation coppice (SRC) strips alternate with strips of annual field crops (see Fig. 6). In addition a reference field without SRC strips but with identical crop management is available.

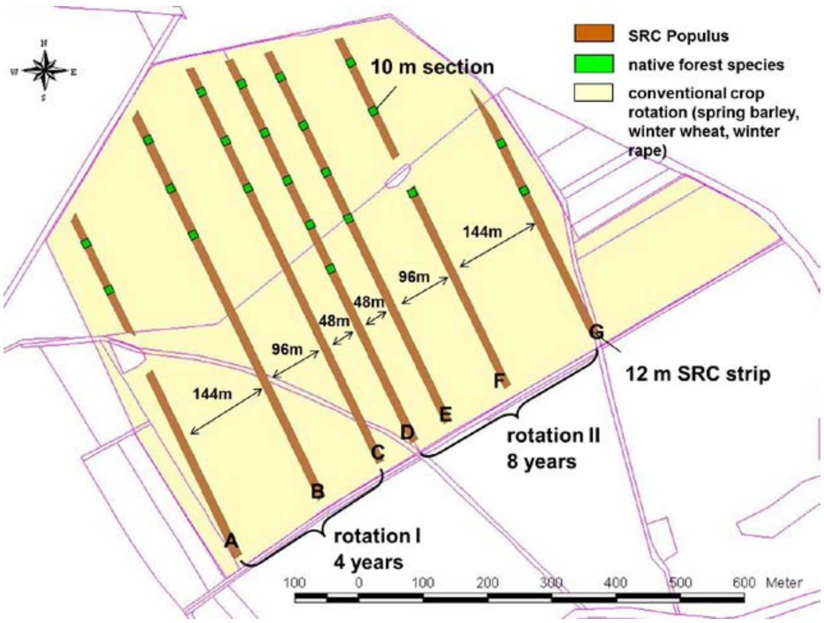

Figure 6: Basic design of the alley cropping system Dornburg

Results of the project AgroForstEnergie indicated that 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. Areas with reduced water availability due to high evaporation levels seem to benefit particularly 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 a reduction of erosion risk. 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.

5 most relevant publications:

Bärwolff, M.; Jung, L.; Vetter, A. (2014): Begleitvegetation eines Energieholz-Agroforstsystems – Eine Bewertung hinsichtlich Biodiversität und Ertragsbeeinflussung. In: Mitteilungen der Gesellschaft für Pflanzenbauwissenschaften 26: 56-57.

Jung, L.; Bärwolff, M.; Vetter, A. (2014): Evolution of crop yields and qualities in a short rotation coppice alley cropping system in Germany. In: 2nd European Agroforestry Conference - Integrating Science and Policy to Promote Agroforestry in Practice, Book of Abstracts, S. 161-164.

Bärwolff, M. (2013): Streifenanbau in Agroforstsystemen. In: Bemmann, A. & Butler Manning, D. (Ed.): Energieholzplantagen in der Landwirtschaft. Erling Verlag, ISBN: 978-3-86263-081-3.

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Detailed description of the work plan

TP6 will concentrate on the inputs and outputs of above-ground biomass at the core plots. Research activities will be conducted in the silvo-arable alley cropping system Dornburg and will use similar methods as the groups conducting the biomass estimates at Reiffenhausen (TP2-2), Wendhausen (TP5) and Lausitz (TP7). Additionally, TP6 has the task of providing logistical support for research activities of other SIGNAL TPs on the Dornburg alley cropping system. To spread information about the concept of modern agroforestry systems and latest research findings of SIGNAL to farmers, agricultural stakeholders and administration, TP6 will be present at field days and organise site visitations as well as publish easily understandable practical information. To ensure a two-way information flow, suggestions, problems and hindrances from the farmers' point of view will be gathered, evaluated and provided for the researchers in partner TPs of SIGNAL as well as published to reach responsible decision-makers.

Annual crops: The amount of aboveground biomass output from crop strips is quantified during harvest. Yield estimation and mapping will be done with GPS-equipped harvesters. The spatial distribution of yields in dependence of the distance from the tree strips is analysed using GIS. In addition, crop yield and quality parameters are determined at 1, 3, 7, 12 and 24 m distance from the tree strips with 4 replications within each core plot. The following parameters are to be tested by TP5: grain yield (harvest-fresh, weighing), straw yield (harvest fresh, weighing), dry matter content grain (1 day 105°C), dry matter content straw (1 day 105°C), grain:straw-ratio (calculation). The following quality parameters will be analysed centrally by TP5: protein content and starch content (cereals), protein content, raw fat content and glucosinolate content (rapeseed). The same analyses are conducted at 1, 3, 7, 12 and 24 m from the field edge in the reference field, also with 4 replications.

The amount of aboveground biomass input by crop harvest residues is determined at the above mentioned sampling locations. Samples of harvest residue material are collected and sent to Braunschweig (TP5) for central analyses of harvest residue quality parameters (C, N, P, K, Ca, Mg, S).

SRC strips: The amount of biomass output from SRC strips A-C is quantified during harvest in 2018. The biomass weight of each tree row in each SRC strip will be determined by weighing of absolute masses. Quality parameters (C, N, P, K, Ca, Mg, S) of harvested wood will be analysed centrally by TP5. Harvest of SRC strips D-G is planned for 2022. Each year during the dormancy period diameters at breast height (1.30 m) and heights of trees are measured non-destructively.

The amount of aboveground biomass input by tree harvest residues is determined. Samples of harvest residue material are collected and sent to Braunschweig (TP5) for central analyses of harvest residue quality parameters (C, N, P, K, Ca, Mg, S).

Litterfall will be quantified by using litterfall traps. To analyze the spatial distribution of tree litter, traps will be placed along transects into the crop field (1, 3, 7, 12, 24 m distance from SRC strips within the core sampling plots, 4 replications) as well as directly within the tree strip. Quality parameters of tree litter (C, N, P, K, Ca, Mg, S) will be analysed centrally by TP5.

Verwertungsplan

Als unmittelbares Bindeglied zwischen Forschung und Praxis basiert die projektspezifische Verwertung von TP6 (Thüringer Landesanstalt für Landwirtschaft, TLL) ebenfalls auf der sofortigen und langjährig gesicherten Bereitstellung und Betreuung von vorhandenen praxisrelevanten Versuchsflächen für das Projektkonsortium. Die direkte Verwertung fokussiert auf die Übermittlung und praktische Überprüfung des neu gewonnenen Wissens im direkten Kontakt mit der beteiligten Praxis, den angrenzenden Beratungsinstitutionen sowie sonstig beteiligten Akteuren (Kommunen, Naturschutzverbände, Landesbehörden etc.). Auch das TP6 wird analog zu TP5 und TP7 insbesondere die erzielten Ergebnisse zu den Felderträgen so aufarbeiten, dass sie direkt für die diversen Modellierungsansätze im TP7 und 8 genutzt werden können und gleichzeitig als Dateninput in das BonaRes Zentrum Verwendung finden.

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TP6 (Graf, Bärwolff & Vetter)	In- and outputs of above-ground biomass											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment assistance for field installations) **(M)**												
Documentation of agrotechnical management measures **(M)**, incl. data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Start of continuous support for central sampling plots (**M**)												
Harvest of annual crops, determination of crop yields **(M)**, incl. data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Determination of annual quantity and quality of tree litter **(M)**, incl. data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Measurements of tree diameters and tree heights **(M)**, incl. data transfer to modelling TPs (7, 8) and to data base of BonaRes-Centre **(D)**												
Harvest of tree strips, determination of wood yield and quality **(M)**,												
Active participation in field days, organisation of site visitations (**M**)												
Annual project meeting **(M)** and annual / final reports **(D)**												
Manuscript on (1) practical information for farmers and administration and (2) hindrances and suggestions from farmers' point of view written and submitted **(D)**												

TP7 Impact of agroforestry management on the land equivalent ratio

Principal Investigators: D. Freese, R. Hüttl[1]

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Scientific background and current status of research; previous work

Diverse management options for agroforestry systems including variations in area, choice of tree species, harvesting intervals, crop rotations, nutrient supply and residue management are discussed in the scientific literature in relation to climatic and edaphic site conditions and with respect to specific features of local farm management (Batish et al., 2007; Böhm et al., 2014; Mosquera-Losada et al., 2011; Eichhorn et al., 2006; Swamy et al., 2006). Similar to conventional agriculture a sound database is needed for agroforestry systems, to parameterize and develop models that allow for the assessment of yield performance, economic revenue and ecological benefits. In particular, a set of empirical data is still missing in order to carry out comparative analyses of agroforestry with conventional agricultural systems taking into consideration different edaphic and climatic conditions as well as varying management approaches (van der Werf et al., 2007; Palma et al., 2007).

The model "Yield Estimator for Long Term Design of Silvoarable Agroforestry in Europe" (YieldSAFE) was initially designed to predict yield data of both crop and timber of silvoarable agroforestry system of Europe. YieldSAFE describes tree and crop interactions in silvoarable systems according to the components of yield production light and water availability. The resulting yield functions express the temporal dynamics of tree/crop biomass interactions, tree/crop leaf area relations, as well as heat sum and soil water content behaviours over time. The main outputs of the model are the growth dynamics over the growing season and final yields of trees and crops. Daily inputs are temperature, solar radiation and precipitation. Planting density, initial biomass of different tree and crop species, and diverse soil parameters must be specified (Keesman et al., 2011). YieldSAFE is a robust model but very simple compared to other existing bio-physical agroforestry models. YieldSAFE can be adapted to different sites with different climatic and soil conditions. The present model approach will be advanced to represent different realistic situations without expanding the set of variables or equations, by adjusting values of parameters to site-specific conditions of our experimental sites using data from the core plots of the consortium. However, for developing a successful management plan for alley cropping with short rotation coppices (time of harvest, available technology of harvest, sales planning etc.), it is essential to have an accurate estimation of the expected yield biomass in advance, before a harvest. A simple approach was presented by Böhm et al. (2011a) where a tree specific allometric function has been derived using parameters easily to measure such as tree height or stem diameter, which are intrinsic parameters for the YieldSAFE model. However, below ground and above non-woody biomass are not considered so far in the YieldSAFE model. In general, there is still a lack of growth data from agroforestry systems.

Previously we developed a methodology focusing on the comparison of the performance of alley cropping systems for woody biomass production and conventional agriculture in Germany taking into consideration several soil-, water-, and biodiversity indicators (Tsonkova et al. 2014). In this study we identified important input parameters in soil, weather and management categories, which were used as input data to develop a simple tool following an empirical approach. The indicators considered were carbon stock in soil, nutrient use efficiency, erosion by water and wind, seepage rate, nitrate concentration in the seepage water, phosphorus loss, plant diversity, and plant protection products. The importance of the parameters was tested via sensitivity analysis. As a next step scenarios were ranked using partial order ranking which was conducted via the freely available PyHasse software (Tsonkova et al. 2015). The application of partial order ranking enabled the comparison of all scenarios with respect to multiple indicators simultaneously and objectively. As a consequence, scenarios with low values for several indicators at the same time under conventional agricultural management were identified. On the one hand, such scenarios were considered target fields for establishing alley cropping system as the expected contribution to improvement in several indicators was highest. On the other hand, the approach allowed for the identification of sensitive scenarios where changing land use was not advisable.

The main objectives of this TP are to assess tree/crop interactions in AF systems and the effects on yield components through adapting the YieldSAFE model. For this purpose a database of main parameters, such as soil properties, tree and crop species, above-ground biomass, below-ground biomass, and climatic conditions will be created. In addition to site-specific parameters the results of YieldSAFE simulation will be evaluated to identify indicators with significant impact on the ecological and economical assessment of our core agroforestry systems.

Preliminary work and previous achievements of the applicants

The Chair of Soil Protection and Recultivation has a long-term experience (since 1995) in investigating agroforestry systems and short rotation plantations. Research and development are focused on the establishment, management and bioeconomical assessment of new designed agroforestry systems (alley cropping) in strong cooperation with regional farm companies. Alley cropping systems have been firmly established within several national (AgroForstEnergy, INKA BB, AUFWERTEN) and international (AGFORWARD, MFC4Climag) research projects. A fruitful collaboration has been developed with the European and Northern America Agrofrestry Federation, respectively, and the World Agroforestry Centre in Kenia.
The focus areas of research encompass topics related to agroforestry, where various studies have been done: qualitative and quantitive C- sequestration; nutrient availability and nutrient use efficiency, water regime in soil-plant-system, plant physiological aspects of trees, biomass yield and modelling and bio-economical assessment (e.g. ecosystem services).

5 most relevant publications:

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, Vol. 88, pp. 579–591

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Tsonkova, P., Böhm, C., Quinkenstein, A., Freese, D., 2015. Application of partial order ranking to identify enhancement potentials for the provision of selected ecosystem services by different land use strategies, Agricutural Systems, 135, 112-121

Detailed description of the work plan

The management and the investigation protocol of the core plots in Forst/L. (Brandenburg) will be carried out in agreement with the partners of the SIGNAL consortium. TP7 will support the logistics on the core plots in Forst for the installation and operation of the field equipment, the soil and biomass investigations and at harvest. The landowner and manager AG Forst e.G: will provide the involved researchers of our consortium with all necessary assistance to carry out the planned research activities. In the specific case of tree and crop biomass measurements in Forst TP7 will apply the same

methods as in Reiffenhausen, Dornburg, Wendhausen and Mariensee) which will be conducted at the plots of the core design.
The YieldSAFE model for trees and crops will be adapted and tested using the Alley-Cropping-Systems on core sites of the consortium The needed data access will be realized through the strong cooperation with TP1-1 (nutrients), TP1-2 and TP3-2 (water) and especially with the TP2-2, TP5 and TP6 (above ground biomass).
A novel approach will be the overall biomass assessment by the integration of both the specific tree short rotation management and the below-ground biomass of trees and crops, always in relation to water and nutrient availability. YieldSAFE requires long-term data on tree growth for the estimation of growth behaviour. Long-term data may not be available from all study sites of the project. Therefore the above- and below ground biomass of trees will be monitored with non-destructive during each vegetation period within the first 3 years. Destructive methods will be conducted only end of the vegetation period. The first tree rotation on the field in Forst has been completed 2014 and the core plots will be established within the poplar tree stands, which will resprout next spring. Therefore, the method of diameter measurements will differ from those reflected for the other experimental core sites as we will measure the diameter at increments of 10 – 50 and later 130 cm above ground. In addition to the multiple stem increment of resprouting trees at different locations of the core plots will be measured by an array of 15-20 automatic dendrometers (DC 2/3) with data loggers during the vegetation period (April to September). Other parameters measured are tree height, number of shoots and leaf area index.
The coarse root biomass will be determined by rootworm sampling to calculate with allometric relations the ratio of above to below ground biomass (Peichl and Arain, 2007). At the end of the vegetation period the total above- and below ground biomass will be harvested, but outside the core plots. The methods employed for the partial harvest of agricultural crops will be identical to the other core locations.
For the yield model more data (parameters) are required from every core plot site, e.g. soil parameters (soil type, texture, soil depth, nutrient availability) tree parameters tree specific data (stem diameter, number of shoots, leaf area index etc.) and tree management (planting density, rotation period, harvest index) and crop physiological and management parameters. These data will be collected by other partners within the consortium.

Part Modelling Tree
- Calibration and Validation of the yield model for trees using existing Alley-Cropping-Systems on different experimental sites of the project partner; data access is realized by the strong cooperation with TP1, 3, 5 and 6.
- Integration of specific tree behavior = resprouting after harvest = aspect of management tree rotations.
- Extent of the model to nutrient aspects / nutrition of trees = effect of nutrient supply on tree growth (N and P use efficiency).

Part crops
Yield modelling of arable crops (annual and perennial) following the same steps as for trees.

The modelling activities will be realized in cooperation with TP8, which aims to develop a more mechanistically based process model for agroforestry systems. The results of YieldSAFE and Expert-N simulations will be compared on yield basis and other biophysical parameters to achieve an upscaling in combination with a process orientated model approach.

Complex Interactions in agroforestry
Complex interactions between trees and crops will be integrated to calculate the overall yield as input parameter for further bio-economical assessment of the complex Alley-Cropping-System. Furthermore, the model output will allow the calculation of the land equivalent ratio (LER), another input parameter for further socio-economical assessment of agroforestry, which will be carried out by TP4-2. Based on the LER an indicator system will be developed, which allows the optimization and adaptation

of alley cropping to site-specific characteristics. This final task of TP7 will be useful to specify future objectives in the second phase.

The methodology described by Tsonkova et al. (2014 and 2015) is focused on an ecological assessment; however, assessment of economic benefits, such as productivity is crucial for the successful implementation of agroforestry systems. A promising indicator of successful plant growth in agroforestry is the land equivalent ratio (LER) which is already included in the YieldSAFE model. Moreover, indicators like nutrient use efficiency, seepage rate, and nutrient leaching can be easily integrated in the YieldSAFE model to include assessment of soil and water quality. Hence, by incorporating the aforementioned indicators, an integrated ecological and economic assessment can be conducted for diversified farming systems. The results can be validated in the long-term experimental sites available within the consortium. Applying the method of partial order ranking will subsequently enable the objective assessment of economic and ecological benefits. Moreover, at the field level this approach would be useful to compare already established systems, e.g., agriculture, alley cropping and silvopastoral system with respect to the newly produced indicators of economic and ecological benefits. The following tasks are involved: a) incorporate ecological indicators, like nutrient use efficiency, seepage rate, and nutrient leaching in the YieldSAFE model; b) validate YieldSAFE using data from the core plots, c) use partial order ranking to compare existing systems described by multiple indicators to identify the most sustainable land use considering economic and ecological benefits.

The **outcome** (deliverables) of the project will contribute to:

a. Agroforestry system modelling on field scale.
b. Creation of a toolset for quantitative assessment of LER of alley cropping systems, allowing system optimization and identification of conflicting objectives.
c. Identification of need for adaptation of alley cropping systems to site-specific characteristics (climatic and edaphic conditions).
d. Management aspects of alley cropping systems will be evaluated to develop options for balancing ecological benefits with an increased yield

Verwertungsplan

Die direkte Verwertung von TP7 basiert auf i) der Bereitstellung von praxisnahen und dauerhaft angelegten Versuchsflächen, ii) der Erfassung von Daten zu den Ertragsleistungen und sonstigen Randbedingungen für die eigenen Versuchsflächen, iii) der Zulieferung entsprechender Daten aus den benachbarten TPs und iv) dem Einsatz und der Erweiterung des Modells Yield SAFE für die eigenen und alle anderen Acker-/Grünlandstandorte (Dornburg, Reiffenhausen, Wendhausen, Mariensee). Dabei liegt der Fokus zur Verwertung zum einen in der signifikanten Erweiterung der Datenbasis zur Validierung (unterschiedliche Standorte, erweiterter Eingang von u.a. Boden- und Durchwurzelungsdaten), zum anderen in der Herleitung der so genannten "Land Equivalent Ratio (LER)". Diese beschreibt den direkten Mehrwert agroforstlicher Anwendungen gegenüber den jeweiligen Monokulturen und ist damit letztendlich die entscheidende und überzeugende Größe für die Einführung (direkter ökonomischer Anreiz) und langfristige Umsetzung (lohnende, dauerhafte Investition) in der landwirtschaftlichen Praxis. Über die Verknüpfung dieser Modell- und Auswertungsansätze in TP7 mit den Aktivitäten des BonaRes Zentrums ergeben sich innovative Ansätze zur Bewertung, Überprüfung und standortsübergreifenden Umsetzung neuer landwirtschaftlicher Bewirtschaftungsmethoden.

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TP7 (Freese & Hüttl)	Impact of agroforestry management on the land equivalent ratio											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student and student assistance for field installations) **(M)**												
Literature review and evaluation of existing field data on growth, climate and plant parameters (**M**), set up of database for modelling (**D**)												
Site specific installations of field plots completed (**D**)												
Data analyses completed and entered in database (**D**), calibration and validation of model with field data from alley cropping study sites (**M**)												
Integration of multi-stem trees in the YIELD-SAFE model approach, LER calculations and LER optimization for different alley-cropping systems (**D**)												
Integration of data on water and nutrient use efficiency as well as litter turnover in the modelling approach (**D**)												
Site specific stakeholder interactions (**M**)												
Annual project meeting **(M)** and annual / final reports **(D)**												
Manuscripts on (1) tree yields, (2) arable crop yields and (3) LER optimization for different sites and growing conditions written and submitted **(D)**												

TP8 Modelling agroforestry systems

Principal Investigator: E. Priesack[1]

[1] Helmholtz Zentrum München

Scientific background and current status of research; previous work

Numerous agricultural and silvicultural models were developed during the last 50 years (Pretzsch et al. 2008, Priesack and Gayler 2009). However, only few agro-forestry models have been made available since the last two decades (Dupraz 2002, Palma 2002). As far as these models are bio-physically based, the involved process descriptions are rather simple and mostly taken from agricultural and silvicultural process-based stand-level models and complemented by descriptions of processes that are specific to tree-crop interactions such as shading or competition for water and nutrient resources (cf. among others: Brisson et al. 1998, van Noordwijk and Lusiana 1999, Mobbs et al. 1999). The more recently developed agro-forestry model Yield-SAFE (van der Werf et al. 2007) aims to simulate agroforestry stands in an even more simplified way based on the calculation of only 7 state variables: biomass and leaf area of both trees and crop, shoot number of trees, heat sum and available soil water. Thus, a robust model is made available to estimate primary biomass production of agroforestry systems by rather simple representations of soil-plant processes at the regional scale (Graves et al. 2007). In contrast to more complex functional-structural, often individual plant based agricultural crop and silvicultural stand growth models (García-Barrios et al. 2001, Gayler and Priesack 2005, Bohn et al. 2014), no such models exist for agro-forestry systems. Furthermore, soil processes in available agro-forest models are described in a very simple way, often assumed to be homogeneous for the total root zone. Different soil horizons and their different soil physical, hydraulic and bio-geochemical properties and differences of soil organic matter pools and their turnover rates are not considered.

Therefore, to better account for the complex interactions between soil biota, nutrient cycling, water uptake and plant growth, a more mechanistic and more dynamic description of water flow, nutrient transport and resource allocation in soil-plant systems is needed. This is in particular important if mixed crop systems are considered to evaluate their sustainability. The objective of this subproject therefore is to describe the different investigated agro-forestry systems by use of an improved process-based soil-plant system model in an integrative way. It is the aim to explicitly simulate water flow and nitrogen uptake in the tree and crop plants including the dependent carbon allocation and plant residue turnover in the soil and at the soil surface. By simulations and scenario calculations we will test and analyse the central project hypotheses based on the experimental findings. Conditions will be identified under which – in contrast to conventional agricultural systems – the considered agro-forestry systems can increase the net value of ecosystem services by improving soil fertility through higher input of crop residues and enhancing nutrient turnover in the soil-plant systems. Also beneficial effects of agro-forestry systems to adapt agricultural crop systems to climate change will be assessed.

Preliminary work and previous achievements of the applicants

The applicant is the main author of the terrestrial ecosystem model Expert-N (Priesack 2006). The model system Expert-N provides a modular modelling platform and includes different sub-models of plant growth and of water flow, heat transfer, carbon and nitrogen transport and turnover in soil and plants (Priesack et al. 2006). The different sub-models already enable the simulation of agricultural, grassland and forest systems. The model system is currently applied to estimate wheat and maize growth under climate change conditions at different field sites throughout the world (Asseng et al. 2013, 2015, Bassu et al. 2014, Martre et al. 2015), it is used to simulate transpiration of forest and grassland sites (Bittner et al.

2010, Hentschel et al. 2013). For forest stands the simulations can be based on explicit description of sap flow in single trees to account for the impact of different tree species on the water balance of forest stands using tree architectures obtained from 3D laser scans (Bittner et al. 2012, 2012a, Hentschel et al. 2013) . Also based on individual plants, the plant growth model PLATHO (Gayler and Priesack, 2005), which is a sub-model of Expert-N, can simulate competition and facilitation between different plants (Gayler et al. 2006) including herbaceous and woody species.

5 most relevant publications:

Asseng, S., Ewert, F., Martre, P., Rötter, R.P., Lobell, D.B., Cammarano, D., Kimball, B.A., Ottman, M.J., Wall, G.W., White, J.W., Reynolds, M.P., Alderman, P.D., Prasad, P.V.V. , Aggarwal, P.K., Anothai, J., Basso, B., Biernath, C., Challinor, A.J., De Sanctis, G., Doltra, J., Fereres, E., Gayler, S., Hoogenboom, G., Hunt, L.A., Izaurralde, R.C., Jabloun, M., Jones, C.D., Kersebaum, K.C., Koehler, A.-K., Müller, C., Naresh Kumar, S., Nendel, C., O'Leary, G., Olesen, J. E., Palosuo, T., Priesack, E., Eyshi Rezaei, E., Ruane, A.C., Semenov, M.A., Shcherbak, I., Steduto, P., Stöckle, C., Stratonovitch, P., Streck, T., Supit, I., Tao, F., Thorburn, P., Waha, K., Wang, E., Wallach, D., Wolf, J., Zhao, Z., Zhu, Y. (2015): Rising temperatures reduce global wheat production. Nature Climate Change, accepted.

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Detailed description of the work plan

We will apply and further develop the terrestrial ecosystem model Expert-N to extend and combine available process descriptions to build an agro-forestry model. This will be achieved by the following work parts (1-5). Specific emphasis is on the soil-plant interaction and its impact on soil water flow, solute transport (C-, N- and P- compounds and N-leaching) and turnover of soil organic matter and related mineralisation of C-, N-, and P from plant litter.

Part 1 Process-based individual plant scale growth modelling: In a first step we will apply the Expert-N sub-model PLATHO (Gayler and Priesack 2005) to describe growth of trees and agricultural crop plants at the individual plant level. For this purpose we need to characterise plant architectures of small plant groups of trees and agricultural crop to explicitly simulate light attenuation and plant internal water flow (following Bittner et al. 2012, which further determines simulation of leaf photosynthesis and nutrient uptake and consequently plant growth.

Plant architectures will be derived from laser scans obtained twice a year for each field site, first during the vegetation period, e.g. during flowering of the agricultural crop (BBCH DC 65) and second after harvest and leaf fall of the deciduous trees. Below-ground root architectures are estimated by applying a root architecture L-system model (Leitner et al. 2010) using basic root characteristic parameters such as root depth and root density distribution as input. Based on the 3D architectures we will simulate facilitation and competition between individual plants for light, water and nutrients in plot sections of intercropping systems (based on the agroforestry plot experiments), in particular shading by trees and possible hydraulic redistribution will be identified (in cooperation with TP3-2). Simulated sap flow and evaporation will be compared to observations obtained by TP1-2.

Also enhanced litter and soil organic matter turnover in the strip and transition zone between trees and agricultural crop due to differences in C-input, soil structure and water regimes including preferential flow, e.g. through earth worm burrows (c.f. TP2-1), will be considered. This will be achieved by applying the Expert-N sub-models for bi-modal water flow and dual-porosity solute transport MUNETOS (Priesack 2006) in combination with the Expert-N sub-model SOILN of soil organic matter turnover and DOC transport (Priesack 2006). The dual-porosity approach will be applied and tested for the intensively monitored plots, where carbon pool and flux data are made available by TP3-1 and TP3-2.

Part 2 Development of a new canopy scale agro-forestry model: Based on the plot scale simulations in WP1 we will develop and parameterize a new agro-forestry model that combines tree growth and crop respectively grass growth models assuming three different growing zones: (i) tree strip zone, (ii) transition zone between trees and crop/grass and (iii) crop/grass land zone to simulate complete field scale agro-forestry system. It is the aim to combine already existing well established growth models (implemented as Expert-N sub-models) in a way that the three different growth zones are adequately represented, in particular concerning differences in abiotic and biogeochemical drivers. The sub-models include the tree growth model TREEDYN3 (Bossel 1996), the agricultural crop models CERES (Ritchie et al. 1987), SPASS (Wang and Engel 2000), SUCROS (van Laar et al.1997), GECROS (Yin and van Laar 2005) and the Hurley-Pasture grass land model (Thornley 2001) and the soil models HYDRUS (Simunek et al. 1998) of water flow and solute transport and soil organic matter turnover (see WP3). The interaction between the growing zones will be described by functional relationships (e.g. for shading) derived from the individual plant based simulations (WP1).

Part 3 Modelling N-leaching and turnover of litter and soil organic matter: Soil organic matter turnover and specific crop residue management will be modelled for the different growing zones by applying the organic matter turnover models SOILN (Johnsson et al. 1987) and CENTURY (Parton et al. 1987) and the Expert-N surface litter turnover model (Berkenkamp et al. 2002) which will be adapted to include tree litter, such as twigs, branches and specific fruits, and extended to include P-mineralisation. The model development will be based on results from TP1-1, where data on N and P mineralisation and availability are obtained. Litter decomposition rates will be derived from labelling experiments of TP2-1 including estimates of microbial activity needed for model parameterisation. N-leaching with water flow below the root zone will be simulated based on simulated N-mineralisation and plant N-uptake and based on soil water flow simulation considering root water uptake from the dynamically growing plants in the different growing zones (in cooperation with TP1-1).

Part 4 Model testing and uncertainty analysis: The model will be parameterized and tested using experimental data obtained by TP1-TP6. Testing is viewed as continuous process. It needs to be repeated when either new data have been acquired or parts of the model have been changed significantly. Simulated water exchange between land surface and atmosphere (evaporation, transpiration, interception) will be tested for agroforestry and agricultural fields using evapotranspiration data from EC measurements and compared to simulated evapotranspiration by the SVAT model (in cooperation with TP1-2). Simulated C- and N-input into soil via plant litter and root exudates will be checked using data of TP3-1, TP2-1 and TP5. Biomass growth and yield quantity and quality data measured in TP2-2, TP4-1, TP5 will be used to verify simulated yields (production of wood, grass biomass, grain or seeds). Furthermore simulation results of primary biomass production and yield obtained by the application of the new Expert-N agro-forestry model and of the YieldSAFE model will be compared (in cooperation with TP7) to assess the system productivity estimates obtained from the new and more mechanistically based process descriptions of the new Expert-N agro-forestry ecosystem model.

Model development and evaluation will be accompanied by regular uncertainty analysis (UA). UA is the quantification and analysis of the uncertainty in the output of models. Uncertainty in model output originates from uncertainties in parameter values, driving variables and model structure, which each have to be quantified.

Part 5 Scenario studies will be performed to analyse possible impacts of various management options (choice of tree vs. crop area, of tree and crop species, of crop rotations, harvesting intervals, exposition) on soil properties and ecosystem services (increase of biodiversity, C-sequestration, reduction of nitrate leaching, flooding and soil erosion). Simulated periods vary from 3-10 years depending on the tree and crop species considered.

Overall, the work package will provide evaluated data sets and model interfaces that can be integrated and applied by the future BonaRes Model Center via the model platform Expert-N.

Verwertungplan von TP8

Das TP8 bildet i) das Bindeglied zwischen den beteiligten TPs des Projektkonsortiums SIGNAL sowie ii) die Schnittstelle zur Kooperation mit dem BonaRes Modell Zentrum. Bezüglich der Verwertung bedeutet dies, dass die in den einzelnen TPs erzeugten Ergebnisse dem TP8 für spezielle Modellanwendungen (z.B. Expert-N) zur Verfügung gestellt werden und hier für entsprechende Simulationsläufe aufgearbeitet und eingesetzt werden. Über die Ergebnisse der Modellläufe selbst und mittels Validierung (Simulation versus wiederholte Feldmessungen von z.B. Erträgen) findet eine Rückkopplung zu den jeweiligen TPs statt. Damit soll gewährleistet werden, dass die aus den Modellsimulationen abgeleiteten Handlungsanweisungen (z.B. spezifischer Düngemitteleinsatz, Änderung der Frucht oder Fruchtfolge etc.) einen praxistauglichen Stand erreichen und beispielsweise lokale Bewirtschaftungsstrategien entsprechend angepasst werden. Dabei liefern die Ergebnisse der Modellläufe selbst eher einen kurzfristigen Einblick in die Interaktionen der beteiligen Expertisen und Fragestellungen (z.B. Einfluss der anfallenden Streu oder Ernterückstände auf den N- und C-Haushalt, Ertragssteigerung oder Minderung durch Interaktionen der Durchwurzelung). Mittel- bis langfristige Verwertungen aus dem TP8 finden über die Kooperation mit dem BonaRes Modell Zentrum statt. Hier werden langfristige Strategien z.B. zur Förderung von agroforstlichen Maßnahmen auf der Landschafts- bzw. Bundesebene erarbeitet oder auch Handlungsanweisungen mit Blick auf z.B. den Klimaschutz, die Klimaveränderung oder die Kohlenstoffspeicherung abgeleitet.

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TP8 (Priesack)	Modelling agro-forestry systems											
Years	**I**		**II**				**III**				**IV**	
Milestones (M), Deliverables (D) *Quarters*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*
Completion of working group (employment of PhD student and student assistance) **(M)**												
Laser-scans for tree architectures (spring and autumn) obtained and analysed for all SIGNAL plots (**M**)												
Individual plant based agro-forestry model for photosynthesis, transpiration and nitrogen uptake of trees and crop developed and tested (**M**)												
Simulation results of soil water flow, nitrogen transport and soil organic matter turn-over compared with experimental data (**M**), incl. resp. scenario analysis (**D**)												
Simulation results of new agro-forestry model for biomass growth and yields com-pared with experimental data (**M**), incl. resp. scenario analysis (**D**)												
Sensitivity analysis for important model parameters (for all versions of the new agro-forestry model) (**D**)												
Agro-forestry model made available as sub-model of the Expert-N model platform and delivered to BonaRes-Centre **(D)**												
Annual project meeting **(M)** and annual / final reports **(D)**												
Manuscript on (1) 3D model results and up-scaling, (2) new agroforestry model ap-plications and (3) model documentation written and submitted **(D)**												