Social and Technological Transformation of Farming Systems:

Diverging and Converging Pathways

Proceedings of the 12th European IFSA Symposium
12th - 15th July 2016 at Harper Adams University, United Kingdom

Volume 2

Andrew Wilcox and Karen Mills (Eds.)

Harper Adams University

IFSA International Farming Systems Association Europe Group

Workshop 3.3: Pathways for land-use: the sustainable avenue of agroforestry

Convenors: Paul Burgess, Jo Smith, Rosa Mosquera Losada, Mike Strachan, Helen Cheshire, Dirk Freese, Piero Paris and Jim Waterson

Society requires land managers who can profitably provide food, fibre and bio-energy in a socially and environmentally responsible way. In the context of increased demands on land use, this workshop argued that segregating land use into either “agriculture” or “forestry” is self-defeating. For individual businesses, practices such as wood-pastures, grazed orchards, biofuel hedgerows, shelterbelts, woodland eggs and woodland grazing can provide additional revenue and often welfare benefits. At a landscape level, appropriate integration of trees with farming can increase carbon storage, reduce runoff and nitrate leaching, and enhance biodiversity. This workshop sought presentations from potential speakers who are successfully integrating trees with farming. Locally, this was anticipated to include work by the Woodland Trust and Harper Adams University on tree browsing on dairy farms and the use of shelter-belts. Within Europe, the workshop sought presenters from research projects such as “AGFORWARD” which is promoting agroforestry and working with about 800 farmers and other stakeholders across 15 countries and 26 institutions across Europe (www.agforward.eu). We invited presentations on the technical, economic, social or policy aspects of agroforestry, and particularly welcomed presentations which emphasised practical applications.

Consumer perceptions and behaviours regarding traditional pork products from agroforestry pigs in Veneto region (north-east Italy)

Bondesan, V.[1], Sartori, A.[1], Ricardi, F.[1] and Burgess, P.J.[2]

[1] *Veneto Agricoltura, Regional Agency for Agriculture, Forestry and Food Sectors, Italy*
[2] *Cranfield University, UK*

Abstract: Outdoor free-range pig production is rare in the Veneto region of Italy and where it exists it is mainly linked to organic farming. Farmers who use agroforestry systems for pig production often process a large proportion of meat on-farm and they expect to receive a premium price from consumers for products such as traditional fermented salami. In order to understand consumer perceptions and behaviours towards agroforestry pigs, an investigation was undertaken which involved 387 consumers associated with nine local fair-trade groups that usually purchase products directly from farms. Although this sample does not represent all consumers, it provides information about consumers choosing "environment-friendly agriculture" such as organic or agroforestry systems. Questionnaires composed of 12 specific multiple choice questions plus questions, for example, regarding age, activity, education and income were completed by consumers who had just seen a brief presentation on the main benefits of agroforestry systems for environment, pig welfare and product quality. Preliminary results indicated that the majority of respondents (74%) knew little about the positive effects of agroforestry. Nevertheless they were interested in the capacity of trees to reduce nutrient leaching in the soil and water (67%), increase carbon storage (43%) and improve pig welfare (37%). Agroforestry applied in an organic farming context appeared to be more valuable than agroforestry applied with conventional agriculture. People who had already eaten farmhouse fresh pork and processed salami from an outdoor free-range organic system thought that the quality was better than similar factory-produced products available in conventional retail shops and supermarkets. A majority of them (68%) believed that higher quality traits depend mainly on breed, feeding and processing techniques, whilst 23% thought that quality was linked to the presence of trees, improved welfare and a "natural" environment. Three main consumer groups were identified in terms of the responses to premium prices. A majority (54%) was unwilling to pay a higher price, a second group (34%) was willing to pay an additional 10-15%, and only 12% were willing to pay a premium of 20-25%. Answers about the premium price are not surprising considering the high price of farmhouse organic salami which costs about 30-50% more than similar organic products in a specialised retail shop. However, a small premium price (10-15%) could be achieved by farmers who promote organic agroforestry systems for fattening pigs if combined with an appropriate information campaign for targeted consumers.

Keywords: Consumers, agroforestry, pigs, salami

Introduction

Farm pork processing and salami production have a long history as traditional Italian agricultural activities (Grazia et al., 2011) to supply food for family use or for sale in local markets. Although pig production intensification and new hygiene rules covering processing have negatively affected traditional production, recently there has been an increased market demand for farmhouse salami. In the Veneto area in north east Italy, farm pork processing and salami production have been increasing steadily over the last fifteen years. This production is mainly associated with multi-functionality farm activities such as agri-tourism including the development of restaurants and farm shops. More recently a Regional law (DGRV n. 1070/2015) has supported an earlier initiative to promote conservation of traditional farmhouse food processing and redefined indications and procedures for farm product processing (such as salami, honey, vegetables and bread) under the control of a local health authority. As regards pork, each farm can process a maximum of 30 fattened heavy pigs (that have to be grown and fattened on farm) during the cold season (from November to February) according to traditional practice. In the Veneto area, there are fermented salamis and not-fermented salamis (made with a single anatomic cut of meat such as from the neck region, in the "*ossocollo*"). The recipes change from one area to another, using different spices (such as black pepper, garlic and fennel seeds) or mixes of meats (pork and sheep or pork and beef, especially in the mountain areas), or different periods for ripening and maturing.

On these farms, piglets are bought at 35-50 kg from sow-farm units, normally during late winter or early spring, and fed until they reach 180-200 kg or more. This takes 9-10 months depending on the breed and the feed. Pigs are kept indoors with free access to a large paddock or outdoors in a free-range system, in one or more groups, and fed *ad libitum* or restricted depending on weight. Outdoor free-range systems have become more common recently due to the lower costs for animal huts, manure management and better standards of pig welfare and with more "natural and traditional" attributes which meet general consumers' requirements. While kept outdoors, growing pigs normally use marginal or less productive areas either in lowland or low mountain valleys. The pasture often includes existing areas of bushes and trees. In designed agroforestry systems, specific trees grown for bio-energy such as poplar, black locust, or willow can be intercropped with grass or arable crops such as peas, barley and sorghum.

There is an increasing interest in agroforestry for pig production; both conventional and organic farmers, who have participated in stakeholder workshops, are willing to establish agroforestry systems to fatten pigs (Bondesan, 2014). They have highlighted that integrating trees can improve pig welfare during hot weather (due to shade reducing temperatures and the provision of stimuli for rooting behaviour), help reduce the leaching of manure nutrients and, in some cases, the trees can provide fodder (including chestnuts and acorns) in the autumn-winter months.

Perceived negative aspects of agroforestry pig production include an increased complexity of work (handling pigs, feeding management) as well as the possible interaction with wild boars (with safety risk for the products) and young tree damage (from rooting, scratching and cork baiting). Farmers who implement agroforestry for pigs normally expect to receive a premium price for their pork products, mainly from consumers who put specific value on "animal friendly and more sustainable agriculture" systems. However that expectation may not be achieved considering the very competitive market segmentation for "high quality" meat products and the existing stratification of protected designation of origin (PDO), protected geographic indication (PGI), and organic quality standards and labels.

Short food chains are the preferred way to sell farmhouse salami, normally through farm shops (while offering other fresh or processed products), local farmer markets, and to solidarity (or fair trade) purchasing groups (SPG). SPGs are particularly attractive to farmers because the groups can encourage production, in terms of quantity and types of salami (during the processing season), they can ensure larger quantities are sold at each purchase, and they can assure purchases through the whole year. SPGs can also help consumers meet their expectations in term of ethical, environmental, and animal welfare standards, whilst providing high quality products at reasonable prices (Brunori et al., 2012; Zander et al., 2013). In the Veneto region, farmer markets have been increasing in popularity in the last five years, thanks to the work of local councils and increased consumer demand for local food (*zero km food origin*). According to Rossetto (2015) the Veneto region boasts about 80 local farmer markets with a large variability in structure, size, the number of days per week, the type of food offered and the number of farmers involved. The report indicates that more than 450 farmers are selling products through farm markets, and about 1.2 million consumers have purchased food there, with an estimated value of €15 million. The most popular products are fresh vegetables (more than 52%), while meat, processed meat (fermented salami) and cheeses reach 10-12% together. It seems more difficult to collect data from the 90 SPG who are operating in the same area; some are quite significant (more than a 100 families-participants) and dynamic (weekly ordering and requiring food delivery) whilst others are small (less than 20 families) and operate only a few times each year for specific purchases such as extra virgin olive oil, fresh meat, or wine. The total of estimated regional value of annual SPG purchases is about €5 million. It is interesting to notice that fresh vegetables still represent a large proportion of purchases (about 60%), but fresh meat and processed salami can reach 30%; this is three times the proportion achieved through farm markets. This suggests that many consumers that choose farmhouse products buy fresh meat and salami through the SPG system.

Objectives and Methodology

An investigation was undertaken that involved nine SPGs of average size (between 42 to 65 families) based in the Veneto area (2015), to identify the issues regarding agroforestry pig production and to find more information about niche consumer interest in pork products. A multiple choice questionnaire was completed by consumers during the SPG general meeting, after a short presentation and discussion about different agriculture and animal production systems.

Data from the collected questionnaires were analysed in order to obtain information on consumer understanding and perceptions about the main aspects of agroforestry and related pork products (preliminary results). Further data on consumer behaviour, derived from the same SPG samples, towards fresh pork and processed salami, will be collected with feedback from farmers and suppliers at the stakeholder panel.

Results

A total of 403 consumers' questionnaires were collected, 387 of them were considered to be correctly filled in and were used for data analyses. A demographic description of the analysed sample is shown in Table 1.

Attitude towards the local food chain

Of the nine SPGs, three were based in a city area (with more than 30,000 inhabitants) and six were based in medium-small towns (with less than 10,000 inhabitants). The consumers from these two groups seemed to have similar purchasing attitudes, although suburban consumers showed a higher monthly purchasing frequency of food from SPG and farm markets than people who live in rural areas (2.8 *vs* 2.3). Generally, they prefer to buy fresh vegetables, fruit, cheese, processed cereals (such as flour and rice) salami and fresh poultry (the whole chicken) approximately once a week at a local farmer market. Selected vegetables and fruits (that are easy to preserve at room temperature in cold seasons, such as potatoes, onions and oranges), bottles of wine, and fresh pork or beef were purchased a few times each year through a SPG. As regards fresh pork, families usually buy it from SPG during the cold season, with an average of 1.6 purchases of 6.8 kg each (usually bags of fresh meat weigh 5 kg, including 4-5 different meat cuts and fresh sausages). The family food basket, from SPG or farm markets, included fermented salami (of different types, size and ageing) every two weeks (23%), once a month (27%) or a few times a year (33%); 17% of consumers sampled do not buy any of them (they do not like the product or are vegetarians). Salami consumption is higher during coldest months; in winter bigger purchases are often programmed (on average 3.6 kg each) because of the large variety of types available on the farm and for traditional winter dishes (such as *cotechino*, a fermented pork rind salami, to be eaten boiled). During spring-summer, salami consumption decreases, and the products are often bought at local farmer markets rather than from SPG; the average purchase is half/one piece of 0.6-0.8 kg in weight.

Table 1. Demographic characteristics of participants (total *N* = 387)

		Count	Proportion (%)
Age	18-30 years	32	8.3
	31-40 years	87	22.5
	41-50 years	123	31.8
	51-65 years	102	26.4
	> 66 years	43	11.1
Gender	Female	220	56.8
	Male	167	43.2
Cohabitation	Single	46	11.9
	Living with family	341	88.1
Number of persons in household	1	46	11.9
	2	93	24.0
	3	136	35.1
	4	98	25.3
	5 +	14	3.6
Number of children (under 14) in household	0	122	31.5
	1	143	37.0
	2	79	20.4
	3	32	8.3
	4 +	11	2.8
Gross annual household income (Euro)	Below 25,000	27	7.0
	25,000-34,999	96	24.8
	35,000-49,999	144	37.2
	50,000-64,999	78	20.2
	65,000 and above	42	10.9
Education	Up to 8 years of schooling	46	11.9
	9 or 10 years of schooling	73	18.9
	13 years of schooling	182	47.0
	Higher education (university)	86	22.2
Occupation	Unskilled labour	28	7.2
	Skilled labour	96	24.8

	White-collar	81	20.9
	Self-employed	44	11.4
	Helping in family business	37	9.6
	Unemployed	25	6.5
	Retired	58	15.0
	In education	18	4.7
Area of residence	Rural	223	57.6
	Urban	164	42.4

As expected, gender and age differences were also observed as regards consumption; female and younger consumers show a lower attitude and preference for traditional salami, probably due to health reasons such as considering salami to be too fatty or salty.

Understanding of low input and organic agriculture

The majority of sampled consumers (72%) prefer local food chains, since they associate those products with positive quality traits and consider them to be fresher, less manipulated, coming from a sustainable system and reliable farmers; in addition, competitive prices may be obtained buying stock through SPGs. However, only 37% of consumers clearly understood the differences between low-input, organic and conventional systems. In fact, the majority of them seemed quite confused when other aspects of food production systems were included and discussed. The remaining 27% of sampled consumers would buy food only from organic farms, especially fresh vegetables, fruit and processed cereals; for them organic standard specifications are quite clear and well defined. The main standard of organic production of "no chemical fertilisers and pesticides use" was often mentioned as a link between safe and healthy products, and it represented a key reason in purchasing decisions.

As regards food of animal origin (fresh or processed) consumers usually perceive less differences between low-input and organic systems; it seems that concepts such as "no GMO feed", "free-range rearing" or "local breed" as well as "grazing system" acquire more importance than official standard certification and labelling. Again the sample consumers showed gaps in knowledge when items such as "type of veterinary therapy", "animal welfare" and castration of male pigs were discussed.

Understanding of the benefits of agroforestry

Agroforestry was considered a new production system by the large majority of the interviewed consumers (74%), and they were able to understand the main positive effects on the environment, products and farming. Systems efficiently combining trees and crop production, or tree-shrub areas for animals, were more appreciated by the "older", "higher educated" and "organic driven" consumers. Consumers (67%) think that the effects of trees in reducing nutrients leaching in the soil and reducing underground water contamination are "important" or "very important"; 43% of them also identified the positive impact of the carbon storage capacity, although carbon footprint in food production (carbon emissions, greenhouse gas effects) were unclear for the majority of consumers.

In general the consumers were less able to identify other agroforestry benefits such as the improvement of natural biodiversity, soil erosion prevention and the positive impacts on landscape views; all these claims were underlined as "less important" or "not important". The presence of trees (including providing shade and microclimate regulation) to improve animal welfare was considered as a positive aspect (37%).

Understanding the effects of agroforestry on product quality

The large majority of consumers who appreciate fermented salami from farmhouse production have specific desires in terms of quality: good taste and flavour, general product appearance (colour, lean meat/fat ratio) traditional spicy and/or recipe. The use of artificial preservatives (nitrites) or synthetic guts (from collagen preparation), which makes farmhouse salami more similar to manufactured production, were poorly perceived by organic consumers and the most traditional salami eaters. While consumers discussed the interaction between agroforestry and fattening pigs in terms of fresh pork and salami quality, we obtained a large variety of opinions.

The majority of the interviewed consumers (68%) thought that fresh pork and salami quality was most connected ("important" or "very important") to the pig breed, feedstuffs raw materials, feeding regime and processing techniques; only 23% of the interviewed consumers considered improved animal welfare as well as a "more natural" environment and perhaps slower growth associated with agroforestry as a positive condition significantly affecting the final product quality.

However, a large majority (81%) of consumers would prefer to buy pork meat from free range farming, because they deem that a natural fattening system could improve welfare and animal health, and may determine a better meat quality (taste, tenderness, less drip loss). Consumers identified major benefits for salami quality from agroforestry fattened pigs when the black pig breed is used and large silvo-pasturage fields with oak trees are adopted; this happens in other regions (Tuscany, Umbria) where a local pig breed "*Cinta Senese*" is becoming a sort of benchmark for this type of product.

The variability in answers makes it difficult to predict if consumers would pay a premium price for agroforestry pig products, as farmers wish. About half of those interviewed (54%) did not wish to pay a premium price, while 34% would agree to pay 10-15% more; only the remaining 12% of them could afford an extra premium of 20-25%. These results may not be surprising because agroforestry for fattening pigs in Veneto still represents a niche production system. Consumers are largely unware of the system benefits for the environment and animals. Also, farmhouse fresh pork and salami already have a premium price if compared with similar products from conventional retail shops, since the price is about 1.8-2.5 times more expensive.

Discussion

Agroforestry represents a new approach in the Veneto area, mainly characterised by large conventional and intensive crop and animal production. Certainly agroforestry seems to be suitable for small or medium size farms, organic or conventional, that are selling farmhouse fresh and processed products directly to the consumers (for example farm markets, SPGs, and agri-tourism). Although farmhouse processed salami has increased, agroforestry for free range fattening pigs is still a niche production (about 17-20 farms in the Veneto region). Undoubtedly consumers who carefully select farm suppliers according to their ethics and food-nutrition habits, may be interested in the benefits of agroforestry. According to the results of this investigation consumers who like eating traditional farmhouse salami, as well as fresh pork, would prefer products from agroforestry fattened pigs. Nevertheless, the above-mentioned results have shown that the farmers' expectation of obtaining an extra premium price for "traditional salami from free-range agroforestry fattened pigs" seems not to be easily achievable especially because of the expensive price of these products. Probably consumers need more detailed information, for example on farm-field visits, to better understand the general benefits of agroforestry if a price premium is to be achieved.

Acknowledgements
We acknowledge the support of the European Commission through the AGFORWARD FP7 research project (contract 613520). The views and the opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

References

Bondesan, V. (2014). Free-range Pigs with Energy Crops in Veneto. Veneto Agricultura, Padova, Italy. Available at http://www.agforward.eu/index.php/en/free-range-pigs-with-energy-crops-italy.html

Brunori, G., Rossi, A., & Guidi, F. (2012). On the new social relations around and beyond food. Analysing consumers' role and action in Gruppi di Acquisto Solidale (Solidarity Purchasing Groups). Sociologia Ruralis 52(1).

Grazia L., Coloretti F., & Zambonelli C. (2011). Tecnologie dei salumi, Edizioni Edagricole de Il Sole 24 ORE S.p.A. Milano, Italy [in Italian].

Regione Veneto (2015). DGRV n. 1070/2015; Piccole Produzioni Locali venete-PPL: aggiornamento del paniere dei prodotti alimentari; regolamentazione della produzione e della commercializzazione. Bollettino Ufficiale Regione Veneto n. 83 del 28/08/2015 Available at: http://bur.regione.veneto.it/BurvServices/Pubblica/DettaglioDgr.aspx?id=304951

Rossetto, R. (2015). Indagine sull’attività dei Farmers Markets e GAS attivi in Veneto. Veneto Agricoltura, Padova – Italy (personal communication).

Zander, K., Stolz, H., & Hamm, U. (2013). Promising ethical arguments for product differentiation in the organic food sector: A mixed methods research approach. Appetite 62: 133-42. doi:10.1016/j.appet.2012.11.015

Nurturing agroforestry systems in temperate regions: an analysis of discourses for an enabling environment in Flanders, Belgium

Borremans, L.[1,2], Wauters, E.[1,3] and Visser, M.[2]

[1] *Social Sciences Unit, Institute for Agricultural and Fisheries Research, Belgium*

[2] *Unit of Landscape Ecology and Plant Production Systems, Université Libre de Bruxelles, Belgium*

[3] *Department of Veterinary Sciences, University of Antwerp, Belgium*

Abstract: In Flanders, the northern region of Belgium, agroforestry systems are increasingly recognised as a multi-functional land use that can balance the production of commodities with non-material outputs such as environmental protection and landscape amenities. Yet the uptake of agroforestry among farmers remains relatively low despite policy incentives such as a subsidy programme covering 80% of the establishment costs. To study this implementation gap, transition literature was consulted which states that the transition from conventional to more diversified farming systems depends on a fundamental change in not only the structures and practices, but also the cultures of a societal system. Whereas actors and stakeholders may hold a wide range of viewpoints regarding agroforestry (e.g. the form, the feasibility and the desirability), policy initiatives typically only address one form of agroforestry. This could be a reason why current incentive programmes are not very effective. Therefore in this paper we focus on cultures of a societal system, and describe a study design using Q-methodology to examine the different narratives and discourses on agroforestry in Flanders. Furthermore, general discourses and narratives on agriculture and agricultural policy are related to the identified perspectives on agroforestry. This is important since different general discourses on agriculture will create different meanings and interpretations of agroforestry and this can help identify an enabling environment for agroforestry in terms of research, policy, market and economic conditions.

Keywords: Temperate agroforestry, discourses, narratives, cultures, Q-methodology, policy

Introduction

Although the term ‘agroforestry systems’ is relatively new and is often linked to tropical regions, the practice of cultivating trees and crops in the same field is also a traditional form of land use in north western Europe (Herzog, 1998). In Flanders, the northern region of Belgium, examples of traditional integrated land use systems include poplar or willow rows at the border of agricultural parcels and standard fruit orchards with grazing livestock. However, through scale enlargement and agricultural intensification many of the trees on and between agricultural plots have disappeared and as such, traditional forms of agroforestry have declined in the Flemish agricultural landscape (Nerlich et al., 2012). However, in recent decades, agroforestry systems have been increasingly recognised as a multifunctional land use approach balancing the production of commodities (such as food, feed, fuel and fibre) with non-material outputs such as environmental protection and landscape amenities (Smith et al., 2012).

Because agroforestry is increasingly recognised as a sustainable agricultural land use system, able to address current problems in European agriculture related to climate change and dependence on fossil energy and mineral resources, it is currently supported through both pillars of the Common Agricultural Policy (CAP). The Flemish government chose to include this in Flemish agricultural policy and in 2011 set up a subsidy programme that included a payment of 80% of establishment costs. These agroforestry parcels, planted with the subsidy programme, are furthermore eligible as Ecological Focus Areas with a weighting of 1, which means that the surface area of agroforestry parcels counts as greening area at the full rate. Although these measures on first sight seem to be strong incentives for agroforestry implementation in Flanders, farmers' interest in agroforestry remains limited. Between 2011 and 2015, about 100 ha of agroforestry were planted (compared with a target to plant 250 ha of agroforestry by the end of 2013 in the 2007-2013 Rural Development programme).

This suggests that supporting the shift from conventional to more sustainable and diversified practices in agriculture is neither simple nor obvious. Therefore in 2014 a large interdisciplinary research project was initiated in Flanders, with the name 'Agroforestry in Flanders, an economically viable answer to the demand for agroecological production methods?' The aim of this five-year project is to (1) develop feasible and productive agroforestry systems suited for the Flemish context and (2) identify the requirements of an enabling environment that supports the development of this land-use system. The project recognises that, in order to nurture agroforestry systems two kinds of changes are necessary, i.e. (1) multi-domain and (2) multi-level changes, which are closely interlinked. The former refers to the fact that not only farmers but all actors and stakeholders from other relevant domains have to be consulted and taken into account when studying the shift to more sustainable farming systems. The latter refers to the structures-cultures-practices triplet put forward by Rotmans (2006) and van Raak (2009) in transition literature. It considers structures and cultures as system level parameters describing the functioning of the societal systems, whereas practices mediate between them and the underlying level of the actors. In this context a transition is considered a fundamental change in the structures, cultures and practices of a societal system, profoundly changing the way it functions. A summary description of the levels according to Haan and Rotmans (2011) would be:

- *Structures*: the formal, physical, legal and economic aspects involved in restricting and enabling practices;
- *Cultures:* the cognitive, discursive, normative and ideological aspects of functioning involved in the sense-making of practices;
- *Practices:* the routines, habits, formalisms, procedures and protocols by which actors (which can include individuals, organisations, and companies) maintain the functioning of the societal system.

A stakeholder analysis that was executed in the summer and autumn of 2015 in the context of the project resulted not only in the identification of 15 stakeholder groups with respect to agroforestry systems but also gave a lot of clues with respect to structures, cultures and practices enabling or hindering the upscaling of agroforestry. This stakeholder analysis is thus a starting point to research the different levels of the described triplet in more detail, focusing in this paper more on the cultures-level. The stakeholder analysis suggested that between different actors a range of different viewpoints exist on different aspects such as the form, the feasibility, the desirability and the opportunities of agroforestry in Flanders. These could be one of the reasons that current incentive schemes are not very effective, since they focus on and address only one perspective on agroforestry, whereas a wide range of existing viewpoints exists. In this paper we therefore elaborate on a study design making use of Q-methodology to research the different viewpoints on agroecology in Flanders.

Discourses in agriculture and agricultural policy

In the context of this research: perspectives, narratives, viewpoints, cultures and discourses relate to the same thing i.e. the way people are seeing or talking about something, and which reflects underlying worldviews and paradigms (Barry & Proops, 1999). More formally we consider here the interpretation of Frouws (1998) who defined discourses as "*an organised set of social representations, the terms though which people understand, explain and articulate the complex, social and physical environment in which they are immersed*". Until now, discourse analysis has been particularly useful in analysing the visions that underlie the different definitions and approaches to farming and sustainable development in agriculture. As such, a range of articles has been published about, for example, rurality perspectives of agricultural stakeholders (Frouws, 1998), farmer management styles (Fairweather & Keating, 1994), and environmental perspectives of farmers (Davies & Hodge, 2006).

Since general opinions about agricultural food production and policy also have an important influence on the view on specific agricultural practices such as agroforestry, it is also very useful to look at some general discourses in more detail. Two general narratives with respect to agriculture and sustainable food production are given by Freibauer et al. (2011). They distinguish between the productivity narrative and the sufficiency narrative. Although both narratives endorse the fact that world population is growing, the two narratives relate it to different problems and solutions (Freibauer et al., 2011):

1. *Productivity narrative:* world population will increase whereas agricultural productivity is slowing down because of resource constraints and climate change. Hence, there is a serious threat that food demands will not be met in 2050, leading to hunger and political instability. New technologies, in particular, can boost productivity by addressing resource scarcities and environmental problems. Therefore investment in research and development, and increased technology adoption by farmers, are the solutions to focus on.
2. *Sufficiency narrative:* World population will increase, which will lead to serious environmental problems resulting in massive health problems, poverty and conflict. More than science, solutions have to be sought in behavioural and structural change in food systems and supply chains. Government also has a role to play by addressing environmental externalities and the disruptive effects of trade.

Both narratives start from the same identification of challenges (increasing world population, scarcity of resources), but are very distinct from each other when it comes to the definition of the problems and processes underlying these challenges and hence also the potential solutions. Therefore both narratives shape how people evaluate what is seen as a desirable evolution of agricultural production systems, and what types of research, technology, markets and policy should surround and facilitate this evolution. The productivity paradigm starts from the observation that food production must drastically increase and – since the resources to do so are becoming scarce and food production causes environmental externalities – it focuses on producing more with less, thus improving the (eco-)efficiency of current production methods. The sufficiency paradigm also starts from the observation that a large number of people have no access to enough food and that this number may drastically increase under the status quo, but unlike the productivity paradigm with looks for causes and solutions in the production of food, the sufficiency narrative focuses more on distribution of food, food systems and consumption patterns. According to this paradigm, the challenge is not to produce enough food, but to produce and market it in such a way that it reaches those that are most needy. This involves the recognition that in some areas of the world there is already enough food, and that the challenge is to produce the same amount of food but in a socially and ecologically better way.

Furthermore Potter and Tilzey (2005) also defined three agricultural policy and market discourses, which structure the selection and operationalisation of policy measures and markets within the agro-food domain:

1. *Neoliberal discourse:* agricultural practices are evaluated along the standards of the global competitive market economy with a focus on economic growth. Therefore farmers are considered real entrepreneurs who have to differentiate, capture value and pursue new opportunities;
2. *Neo-mercantilist discourse*: agricultural development is associated both with protectionism as with a socio-economic solidarity. Rather than an entrepreneur, farmers are considered policy takers which serve national interests by ensuring food security;
3. *Strong multifunctionality*: agriculture has a key role to play in integrating social and ecological processes, which should result in an economically viable agricultural sector. The existing power relationships within the agricultural sector should be rebalanced with a more important role for civil society.

These narratives, paradigms or discourses must be seen as a combination of ideas, opinions and perspectives that give rise to a certain direction of policy frameworks and measures, because they shape what is thought to be the right thing, the problem definition and formulation and what are regarded as good solutions. Erjavec and Erjavec (2009) showed that the neo-liberal discourse was gaining increasing importance, even though elements of the other two competing discourses were sometimes used in communications by the EU Agricultural Commissioner to different audiences.

None of the above discourses have a one-on-one relationship with agriculture and agricultural policy. Dibden et al. (2009), for instance, showed that agricultural policy makers in the EU and Australia were both supporting a type of agriculture driven by the productivity narrative. However, while the EU, although gradually moving towards the neo-liberal stance, incorporated several aspects driven by the neo-mercantilist position (trade barriers, heavily subsidised agricultural sector), Australia has employed instruments driven by a purely neo-liberal position (unsubsidised highly productive agriculture).

These general discourses about agriculture and agricultural policy will be merged with perspectives about agroforestry in this study. The motivation for this is the growing recognition that the different discourses on agriculture and agricultural policy constitute a certain rhetoric that will result in different meanings and interpretations of agricultural practices. As such they also imply differences in the enabling environment of these practices, formed by research, policy, market and economic conditions. This suggests that in practice, stakeholders adhering to different views about agriculture and agricultural policy might hold different or even opposing perspectives about agroforestry, what it is (or should be) and if and how it should be incentivised.

Methodology

Method: Q-methodology

Q-methodology, or in shortened form, Q-method, was primary invented and developed by William Stephenson in the 1930s to assist in the examination of human subjectivity (Brown, 1980). Today Q-method usually implies factor analysis or quantitative correlation analysis, and tries to unravel different perspectives on a particular subject and to measure the overlap and difference between them (Hermans et al., 2012). As such Q-methodology possesses both quantitative and qualitative dimensions (Ellingsen et al., 2010) which makes it an increasingly popular method for identifying different groups and their shared perspectives and to test hypotheses about existing viewpoints in a more quantitative way (Hermans et al., 2012).

Q-method differs from the more commonly known surveys and questionnaires to elicit different discourses. First of all surveys and questionnaires ask respondents to express their opinions on isolated statements, whereas Q-methodology identifies respondents' views on a statement in the light of all other statements presented (Cuppen et al., 2010; Dryzek & Berejikian, 1993). In this way it addresses the fact that the same words or phrases may mean different things to different people, and that statements are generally understood in the context of other statements included in the questionnaire or survey (Hermans et al., 2015). Though, in comparison to surveys and questionnaires which can easily measure the level of support for certain viewpoints, Q-method is more appropriate for giving an overview of the plurality of the different discourses that exist (Cuppen et al., 2010).

A Q-method consists of six general steps. In this and the next section the two first steps in executing a Q-method are explained in more detail. The other steps will be implemented in the near future and are explained more briefly.

Step 1: generating the communication concourse

The first step in a Q-study is to identify the concourse, which refers to the communication about a certain issue, here agroforestry. In general the concourse takes the form of a collection of statements which should capture the full range of viewpoints and perspectives that different stakeholders might have (Hermans et al., 2015).

In this study, the concourse about the potential for agroforestry to become a common farming system in Flanders was created using a combination of several sources. First, we consulted the literature about agroforestry adoption and its wider framing as an agro-ecological farming practice. Therefore we consulted literature about agroforestry, its feasibility in Belgium (e.g. Borremans et al., under review) and literature about agro-ecological transitions (e.g. Duru et al., 2015). Furthermore, we consulted the academic literature and non-academic reports concerning discourses about farming and agricultural policy. The motivation for this is the growing recognition that the adoption potential of a farming system such as agroforestry does not just depend on tangible barriers and drivers related to the practice itself and to farm and farmer characteristics. It also depends on the enabling environment, formed by research, policy, market and economic conditions, including the general narratives on agriculture held by influential stakeholders and institutions that determine and define the structures and practices put into place. This step in the development of the communication concourse was of a deductive nature, meaning that we had a predefined idea that these perspectives may be important and related to the perspectives about agroforestry. Second, we undertook an extensive stakeholder analysis to identify a diverse range of opinions on agroforestry. The stakeholder analysis took place from June to December 2015. Selection of the respondents was firstly based on expert knowledge and participation in previous agroforestry activities. New respondents were then selected through a snowball sampling technique. In total 25 interviews were carried out with the help of interview guides containing questions structured around four themes:

(1) knowledge, feasibility and desirability, and barriers and enabling factors;
(2) impact of agroforestry development on the stakeholder;
(3) influence of the stakeholder on agroforestry development;
(4) other important stakeholders and their characteristics.

After the interviews in November 2015, two focus groups were organised in which 16 people participated. The specific goal of the focus groups was to explore more in depth stakeholders' thoughts and opinions, and uncover new information as respondents now had the possibility of reacting to and discussing with each other. Therefore the focus groups were made as diverse as possible, with an equal distribution of the respondents among the different identified stakeholder categories. The distribution of the 36 respondents that participated in the interviews and focus groups over the different identified stakeholder groups is presented in Table 1. In the end the stakeholder analysis led to the identification of 6 broad groups of stakeholders, but because the stakeholders within a stakeholder group still had a lot of differences with respect to interests in and influence on agroforestry, they were subdivided into 17 smaller, more uniform stakeholder groups (Borremans et al., under review).

Table 1. Distribution of respondents over the different identified stakeholder categories

Stakeholder group	SH subgroups	Number of respondents		
Agriculture	Farmer organisations	5	9	36
	Farmers	4		
Government	European government	0	5	
	Flemish government	5		
	Local government	0		
Research	Euraf-network	0	5	
	Flemish research institutions	3		
	Practical centres	2		
Civil society organisations	Environmental organisations	6	11	
	Landscape organisations	3		
	Transition agriculture organisations	2		
Suppliers and buyers	Suppliers	2	5	
	Buyers	3		
	Processors, supermarkets	0		
Society	Local residents	0	1	
	Landowners	1		
	Consumers	0		

The collected qualitative data were transcribed as soon as possible and afterwards processed and analysed in Nvivo11. For generating the communication concourse all the transcriptions were explored once more. To triangulate the results of this analysis, some secondary sources, such as a range of articles that were published in regional agricultural journals, were examined. This second method to construct the communication concourse was inductive, as we used exploratory qualitative research to identify all possible perspectives about agroforestry. This led to a communication concourse of more than 300 statements.

Step 2: setting up the Q-sort

Since a concourse of hundreds of statements is too large to present to participants in the Q-study, a group of 30-60 statements has to be chosen from the concourse, which is considered sufficient to elicit the different existing points of view (Hermans et al., 2012). For selecting the final group of statements, i.e. the Q-set, two different approaches exist (Paige & Morin, 2014). When no predefined theory exists about the subject of interest an inductive or unstructured approach should be used. In this case, the selection of the final Q-set is based on the different themes that emerge from the communication concourse. When a deductive approach is chosen, the selection of the final Q-set depends on theoretical considerations, i.e. relevant concepts derived from a theory or framework.

In this study design the two different approaches are combined. An inductive approach was used to select statements relating to agroforestry, its definition and different forms, its feasibility and the factors and actors influencing its breakthrough. These statements were primarily drawn from the interviews and focus groups and selection was done (1) based on the level of dissensus that was expected and (2) ensuring that all diverse opinions were represented. A deductive approach was used to add statements that related to the diverse narratives held about agriculture (efficiency, sufficiency) and agricultural policy and markets (neo-liberalism, neomercantilism, multifunctionality). Statements were constructed, as described above, based on an analysis of peer-reviewed papers and reports. In this step statements were selected to represent the whole diversity of different paradigms.

Table 2. Statements selected in the Q-set

Perspectives on agroforestry as a production system (type, scale, definition)	1	In the case of agroforestry, an extra layer, which is the tree component, is slid into your agricultural system with as little impact as possible on the crops
	2	Agroforestry means achieving the highest productivity in function of the circumstances of the plot
	3	Only if it concerns extensive grazed livestock systems are there opportunities for agroforestry systems in Flanders
	4	If you are starting with agroforestry, you must dare to choose poplar; you must dare to choose species with a high yield
	5	Implementing agroforestry solely with wood production as a motive is naive
	6	Standard fruit orchards are too labour intensive to be economically viable
	7	Agroforestry is only useful on less valuable plots that are too small, too wet or too far away
	8	The larger your plot, the more interesting and profitable agroforestry becomes
	9	The correct arrangement of the plot and modern GPS technology allows the farmer to use his agricultural machines in an optimal way
	10	The agricultural business model in Flanders is aimed at scale enlargement and the combination scale enlargement - agroforestry does not fit

Perspectives on the economic, financial and market aspects of agroforestry	11	As long as the profitability of such a farming system is not clear, agroforestry has few opportunities in Flanders
	12	Trees on the farm have completely lost their functionality
	13	Trees reduce the value of agricultural land considerably
	14	Agroforestry is not intended to give hobby-farmers an occupation, it really must be profitable and economically viable
	15	The consumer does not want to pay extra for products originating from more sustainable farming systems
	16	A dynamic where agroforestry could jump on is really the story of farm sales, urban agriculture and community supported agriculture
	17	The added value of agroforestry is that it allows farmers to strengthen their product specificity
Perspectives on the institutional aspects of agroforestry	18	A subsidy serves to compensate the farmer for the application of a socially advantageous but not very profitable farming system
	19	Due to inconsistencies in agricultural policy which changes year after year, farmers don't dare to get involved with agroforestry
	20	The development of agroforestry is very much restrained by the tension between the agricultural and the nature sector
	21	The current evolutions in agriculture, such as seasonal tenancy and the hiring of contractors, rather counteract agroforestry development
	22	The successive crises in agriculture will lead to a transition to other more diversified farm business models with more opportunities for agroforestry
	23	The government should not impose excessive restrictions on how agroforestry is implemented and should pursue a more flexible policy
	24	A law should never be able to come into effect which prohibits harvesting trees planted in an agroforestry system
	25	The fact that agroforestry plots in Flanders are eligible as an ecological focus area, may persuade farmers to opt for agroforestry
	26	The subsidy programme should not just be linked to the trees, but to the farm business model and production plan that are completely adjusted to agroforestry implementation
	27	Farmers should get a higher fee if the trees they plant imply a higher value for society
Perspectives on the socio-ecological aspects of agroforestry	28	The benefits of agroforestry are primarily directed to society rather than to the farmer himself
	29	Not every additional tree planted in farmland also has an ecological or scenic value
	30	A farmer who is innovative, is often viewed with suspicion by his colleagues
	31	A farmer who is 60, will be more reluctant to plant trees than a farmer who is 30
	32	It is not the role of the farmer to experiment with trees
	33	Agroforestry in the sense of rows of tall trees, have a negative impact on wildlife
	34	Trees do not protect against crop diseases, on the contrary, they lead to shade and moisture which makes crops more prone to fungi
	35	Agroforestry in itself is a very nice system, but its benefits are applicable only in the tropics and regions such as southern France
Perspectives on agriculture	36	The whole story about PAS, IHD and Natura 2000 has exacerbated the crisis in agriculture
	37	The most important feature of agricultural innovations should be its effect on productivity of food production

	38	To meet the challenges in the future, it is necessary that farmers should try to produce more food with less inputs
	39	The agricultural sector should try to produce better products, with more care for the social and ecological impact, rather than more
	40	A subsidy programmes serves to start up the conversion to more sustainable agricultural systems, until the market takes over
	41	Farmers receive too few benefits when concluding management agreements or implementing agro-environment measures
	42	Land sparing (improving food productivity per hectare of land at (ecological) costs so more land can be saved for nature conservation and biodiversity) is to be preferred over land sharing (providing both food products and public goods such as biodiversity on the same plot of land, with a possible lower food production per hectare)
Perspectives on agricultural policy	43	The agricultural sector should compete in the free global market, just as any other sector
	44	Farming is different from other sectors, and hence should be protected from the market by governments
	45	The liberalised and globalised market is not working for agriculture
	46	The production of food and the production of other things such as a nice landscape, rural tourism, good environmental conditions should be separated: only food production on farm land, everything else somewhere else
	47	Farmers are not only producers of food, but also stewards of the land and must take into account the environment

Further steps

The third step consists of selecting the respondents. In Q-methodology, in contrast to R-methodology (e.g. regular survey methods), the quality depends less on sample size and representativeness, but more on the extent to which the whole diversity of possible perspectives are captured by the sample. In our study, the respondents will be drawn from the six stakeholder groups defined in Table 1. Afterwards the selected respondents will be asked to rank-order the statements according to a forced normal distribution, with different positions ranging from least to most 'according to my point of view'. In this way it identifies a small number of statements in the extreme categories which characterise the different perspectives the most. This fourth step can be done during an interview, in which the normal distribution is printed on a large sheet of paper and the statements on small cards, or it can be performed online with special software such as the FlashQ software (Hermans et al., 2012). The fifth step encompasses a principal component analysis to rearrange the data by identifying and ordering components and ranking them according to the amount of variance that they explain from the original data. Subsequently a data reduction step will take place by choosing the right amount of components and discarding the rest. The sixth last step consists of an interpretation of the factor scores. Therefore a number of 'ideal Q-sorts' are produced, which will represent the different perspectives or discourses, and around which those Q-sorts which come closest to these ideals are listed. In the end, the different perspectives are interpreted and described, which is facilitated by identifying the most distinguishing statements of the different perspectives (Cuppen et al., 2010; Hermans et al., 2012)

Expected results

The expected results of this study are the identification of – idealised – Q-sorts, which represent a model discourse indicating the perspectives held regarding agroforestry and how they are related with broader perspectives concerning agriculture and agricultural policy. Further, the results can potentially indicate which perspectives are more common among which stakeholder groups. Using this, implications can be drawn regarding the feasibility of agroforestry, its barriers and drivers and how they relate to broader narratives about agriculture and policy. We expect to identify different perspectives regarding agroforestry, and thus different pathways to transform farming systems into agroforestry systems, depending on peoples' perspectives regarding agriculture and policy.

References

Barry, J., & Proops, J. (1999). Seeking sustainability discourses with Q methodology. Ecological Economics 28(3): 337-345. doi:10.1016/S0921-8009(98)00053-6

Borremans, L., Reubens, B., Van Gils, B., Baeyens, D., Vandevelde, C., & Wauters, E. (under review). A socio-psychological analysis of agroforestry adoption in Flanders: understanding the discrepancy between conceptual opportunities and actual implementation.

Borremans, L., Reubens, B., & Wauters, E. (in press). Nurturing agroforestry systems in Flanders : an Agricultural Innovation System approach. In Book of Abstracts: 3rd European Agroforestry Conference, Montpellier, 23-25 May 2016.

Brown, S.R. (1980). Political Subjectivity: Application of Q-methodology in Political Science. New Haven, London: Yale University.

Cuppen, E., Breukers, S., Hisschemöller, M., & Bergsma, E. (2010). Q methodology to select participants for a stakeholder dialogue on energy options from biomass in the Netherlands. Ecological Economics 69(3): 579-591. doi:10.1016/j.ecolecon.2009.09.005

Davies, B.B., & Hodge, I.D. (2006). Exploring environmental perspectives in lowland agriculture : a Q methodology study in East Anglia, UK. Ecological Economics 61: 323-333. doi:10.1016/j.ecolecon.2006.03.002

de Haan, J. (Hans), & Rotmans, J. (2011). Patterns in transitions: understanding complex chains of change. Technological Forecasting and Social Change 78(1): 90-102. doi:10.1016/j.techfore.2010.10.008

Dibden, J., Potter, C., & Cocklin, C. (2009). Contesting the neoliberal project for agriculture: productivist and multifunctional trajectories in the European Union and Australia. Journal of Rural Studies 25(3): 299-308. doi:10.1016/j.jrurstud.2008.12.003

Dryzek, J.S., & Berejikian, J. (1993). Reconstructive democratic theory. American Political Science Review 78(1): 48.

Duru, M., Therond, O., & Fares, M. (2015). Designing agroecological transitions; a review. Agronomy for Sustainable Development 35(4). doi:10.1007/s13593-015-0318-x

Ellingsen, I.T., Størksen, I., & Stephens, P. (2010). Q methodology in social work research. International Journal of Social Research Methodology 13(5): 395-409. doi:10.1080/13645570903368286

Erjavec, K., & Erjavec, E. (2009). Changing EU agricultural policy discourses? The discourse analysis of Commissioner's speeches 2000-2007. Food Policy 34(2): 218-226. doi:10.1016/j.foodpol.2008.10.009

Fairweather, J.R., & Keating, N.C. (1994). Goals and management styles of New Zealand farmers. Agricultural Systems 44(2): 181-200. doi:10.1016/0308-521X(94)90160-H

Freibauer, A., Mathijs, E., Brunori, G., Damianova, Z., Faroult, E., Firona, I., Gomis, J. et al. (2011). Sustainable food consumption and production in a resource-constrained world. European Commission – Standing Committee on Agricultural Research (SCAR).

Frouws, J. (1998). The contested redefinition of the countryside. An analysis of rural discourses in the Netherlands. Sociologia Ruralis 38(1): 54-68. doi:10.1111/1467-9523.00063

Hermans, F., Klerkx, L., & Roep, D. (2015). Structural conditions for collaboration and learning in innovation networks: using an innovation system performance lens to analyse agricultural knowledge systems. The Journal of Agricultural Education and Extension, 21(1), 35–54. doi:10.1080/1389224X.2014.991113

Hermans, F., Kok, K., Beers, P.J., & Veldkamp, T. (2012). Assessing sustainability perspectives in rural innovation projects using Q-methodology. Sociologia Ruralis 52(1): 70-91. doi:10.1111/j.1467-9523.2011.00554.x

Herzog, F. (1998). Streuobst: a traditional agroforestry system as a model for agroforestry development in temperate Europe. Agroforestry Systems 42(1): 61-80.

Nerlich, K., Graeff-Hönninger, S., & Claupein, W. (2012). Agroforestry in Europe: a review of the disappearance of traditional systems and development of modern agroforestry practices, with emphasis on experiences in Germany. Agroforestry Systems 87(2): 475-492. doi:10.1007/s10457-012-9560-2

Paige, J.B. & Morin, K.H. (2014). Q-Sample construction: a critical step for a Q-Methodological study. Western Journal of Nursing Research. doi:10.1177/0193945914545177

Potter, C., & Tilzey, M. (2005). Agricultural policy discourses in the European post-Fordist transition: neoliberalism, neomercantilism and multifunctionality. Progress in Human Geography 29(5): 581-600. doi:10.1191/0309132505ph569oa

Rotmans, J., & Loorbach, D. (2006). Transition management: reflexive governance of societal complexity through searching, learning and experimenting. In Reflexive Governance for Sustainable Development (p. 53).

Smith, J., Pearce, B.D., & Wolfe, M.S. (2012). Reconciling productivity with protection of the environment: is temperate agroforestry the answer? Renewable Agriculture and Food Systems 28(01): 1-13. doi:10.1017/S1742170511000585

Van Raak, R. (2009). Re-defining health systems from the perspective of transition theory. In J.E.W. Broerse and J.F.G. Bunders (Eds.) Transitions in Health Systems. Dealing with Persistent Problems. VU University Press.

Sugar beet yields in an alley cropping system during a dry summer

J. Mirck, M. Kanzler, C. Boehm and D. Freese

Department of Soil Protection and Recultivation, Brandenburg University of Technology, Germany

Abstract: Agroforestry (the integration of trees with crop and/or livestock production) offers a pathway to diversify agricultural production. Agroforestry systems have the potential to improve on-farm use of water through enhanced soil water holding capacities, the provision of shade and the creation of wind shelter. These three characteristics can also improve the resilience of agricultural production in response to changing weather patterns. The objectives of this study were: 1) to measure how alley cropping systems with varying alley widths affect crop microclimate; 2) to measure the effects of this microclimate on sugar beet (*Beta vulgaris*) yields; and 3) to assess how moisture availability affects sugar beet growth patterns. Measurements were made in a 70 ha alley cropping system comprising black locust (*Robinia pseudoacacia L.*) and hybrid poplar Max1 (*Populus suaveolens subsp. maximowiczii x P. nigra*). A sugar beet crop was grown during the relatively dry growing season of 2015. Sugar beet yields were reduced in close proximity to the hedgerow, but yields were higher at and beyond an intermediate distance when compared with those in a nearby conventional agricultural field. Moisture availability significantly affected growth patterns of sugar beet roots.

Keywords: Agriculture, agroforestry, *Beta vulgaris*, microclimate, *Populus* spp, *Robinia pseudoacacia*

Introduction

Silvoarable agroforestry is the mixed cultivation of arable crops and trees on a single parcel of land. It has the potential to combine food, feed, fibre and renewable energy production (USDA, 2011). It is also a land management approach that can maintain or increase productivity and profitability whilst enhancing ecosystem services. Agroforestry can also help control wind and water erosion, minimise water losses from evaporation, reduce nutrient losses, and help stabilise soil organic matter (Quinkenstein et al., 2009).

The State of Brandenburg is known for its light sandy soils that are prone to wind erosion. The introduction of tree hedgerows within the agricultural landscape can reduce wind erosion (Boehm et al., 2014). In addition, microclimatic conditions such as soil moisture, wind speed, relative humidity and air temperature can be more favourable for plant growth in crop alleys compared to reference crop areas (Boehm et al., 2014; Quinkenstein et al., 2009). Evapotranspiration rates can be reduced in close proximity to the trees due to the shelter effect (Monteith et al., 1991; Gruenewald et al., 2009), but the tree and crop components can also compete for light, water and nutrients. The intensity of interactions between the two components is likely to be weather dependent, with water competition being greatest during dry and hot summers.

Agroforestry for arable farmers is not a common practice in Germany. However, alley cropping for woody biomass production is of interest because of the potential to concurrently provide a biomass feedstock and an arable crop. One of the systems, that exists at an experimental level, is the integration of rows of fast growing trees, such as poplar or willow, with arable crops. Water use for cereal crops such as wheat has been studied in a silvoarable system (Burgess et al., 1996), but sugar beet has rarely been researched within the alleys of these systems.

Sugar beet is a common crop within arable systems in Western Europe. As part of agroforestry systems, sugar beets have rarely been studied. Even though sugar beets can root up to a depth of 2 m, their yields can be significantly reduced due to a lack of water (Hoffmann, 2010; Bloch et al., 2006). Agroforestry systems that consist of tree hedgerows and crop alleys, also known as “alley cropping” systems, can increase soil moisture in comparison to conventional agricultural systems (Quinkenstein et al., 2009), and hence such systems, relative to a conventional arable system, could improve sugar beet yields during dry years. This study aimed to assess tree hedgerow effects on sugar beet. The objectives of this study were: 1) to measure how alley cropping systems with varying alley widths affected crop microclimate; 2) to assess how tree hedgerows planted at three distances affected sugar beet yields; and 3) to assess the effects of drought stress on sugar beet yield.

Material and methods

Site description

The study site is located on a 70 ha area of agricultural land owned by the Agricultural Cooperative Forst in Neu Sacro in close proximity to the city of Forst (Lausitz) in Germany. The land has been actively used for conventional agriculture during the last decennia. An alley cropping system in which the tree hedgerows consisted of short rotation coppice fast growing woody crops, poplar (*Populus nigra L.*× *P. maximowiczii* (variety Max 1)) and black locust (*Robinia pseudoacacia*) was established on the site in 2010. The poplars did not establish well during the first year and were replanted in 2011. The sugar beet yield study took place in the western part of the alley cropping system and on a nearby conventional agricultural field (Figure 1).

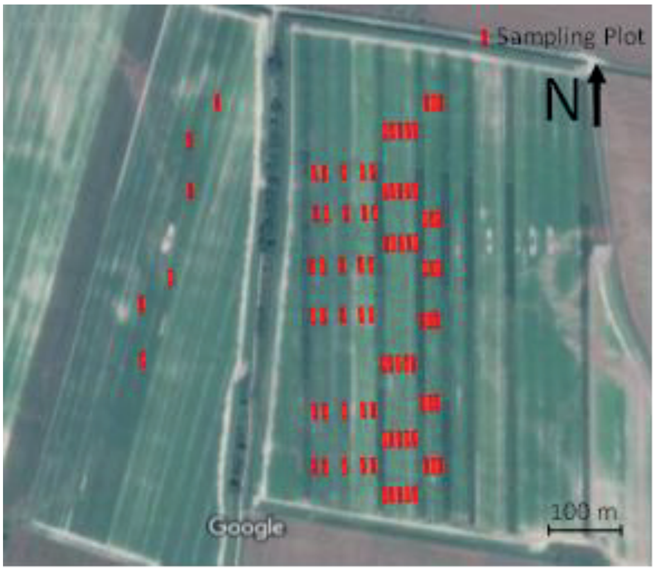


Figure 1. Map of the alley cropping research trial at the Agricultural Cooperative Forst in Neu Sacro (Lausitz), in Germany. Coloured squares indicate sampling plots for the manual sugar beet harvest *(map source: Google Maps).*

The spacing within the hedgerows was four double rows with 75 cm within the double row, 1.8 m between the double rows and 90 cm within the row. The tree hedgerows are 12 m wide, which includes a buffer strip of 1.8 m on both sides. The tree hedgerows were harvested in February 2015. The crop alleys are 96, 48 and 24 m wide. The main soil type is Gley-Vega, with groundwater levels varying between 1 and 2.5 m below the surface. The top soil is a loamy sand and the subsoil pure sand with gravel layers, with clayey areas (Boehm et al., 2015).

Sugar beet yield study

The sugar beet crop was sown within the crop alleys and on an adjacent conventional agricultural field during the middle of April 2015. A manual harvest of sugar beets at the study site took place between 30 September and 6 October 2015. Measurements took place at the three western crop alleys of the alley cropping system (Figure 1). Within the alley cropping system both crops in close proximity to the tree rows and crops in the middle of the alleys were harvested in order to assess tree-crop interactions (Rao & Coe, 1991). For the 96 m and 48 m wide crop alleys crop plots were measured at 3 m, 12 m east and west of the tree row and in the centre of the alley, and for the 24 m wide alley at 3 m east and west of the tree row and in the centre. Six replications were carried out for each treatment. Sampling plots were approximately 3-5 m² in size and consisted of three sugar beet rows. Prior to sugar beet extraction all beets within the sampling plot were counted and the exact plot size was measured. These values were required for subsequent yield calculations. For sugar beet harvest in each of the plots the following protocol was used: 1) above- and below ground biomass of 12 sugar beets were harvested and weighed separately; 2) two sugar beets were collected for dry matter determination. From the two beets for dry matter determination subsamples were stored in ziploc bags and transported to the laboratory where fresh weight was measured and they were dried until a constant weight at 105°C.

Sugar beet drought stress

The effect of drought stress on sugar beet yields was measured through harvesting 10 sugar beets from an area of the field with low water holding capacity and 10 sugar beets from an area with higher water holding capacity. These sugar beets were collected on 19 October 2015. Five sugar beets from each location were sent away to assess sugar (sucrose) content polarimetrically at Institute für Produktqualität (IFP). Pictures were taken from a circular cut of the remaining sugar beets and these pictures were analysed with the software Image J. This software was used to measure diameter and to count the number of cambium rings and their thickness. After the pictures were taken fresh weight of the circular and a perpendicular cut were measured and afterwards they were dried at 105°C until a constant weight and dry weight calculated.

Statistical analysis

Statistical analysis was carried out using SigmaPlot 12.5 (Systat Software GmbH, Erkrath, Germany). Differences in sugar beet yields between the alley cropping system and the conventional crop reference site were assessed separately for each of the alley widths with two-way ANOVAs (Dunnett's method). Differences between the drought stressed and non-drought stressed sugar beets were analysed using t-tests. For all statistical test we used a significance level of $\alpha = 0.05$ unless mentioned otherwise.

Results

Effect of location and alley width on yield

Long dry spells occurred in May, August, and between the end of September and the beginning of October. For the period between May and October 2015, the rainfall received in the reference site was similar to that in the three alley widths, although rainfall total tended to be smaller in the 48 m and the 24 m alleys (Figure 2). A comparison between the monthly precipitation sums between 1985 and 2014 and the measurements in the alley cropping system during the 2015 growing season indicated that May and August were much drier than normal.

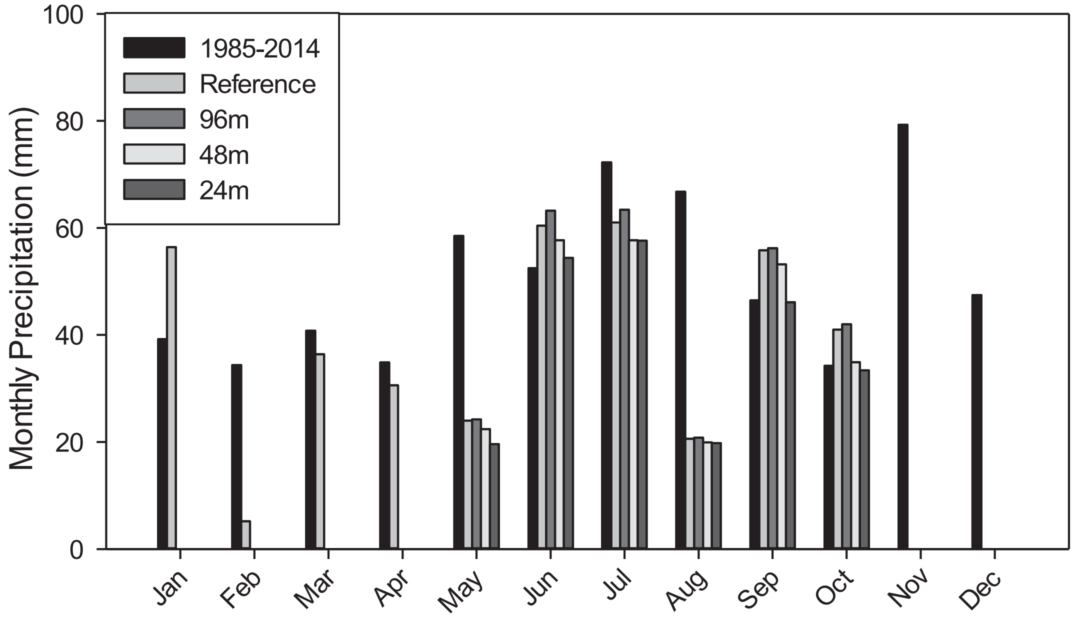


Figure 2. Monthly precipitation (May to October) for the reference and experimental locations within the Alley Cropping System Research Trial site for 2015 with the historical monthly precipitation sums (1985-2014) from a nearby weather station from the German Weather Service in Cottbus, Germany
(ftp://ftp-cdc.dwd.de/pub/CDC/observations_germany/climate/monthly/kl/historical/).

Sugar beet yields tended to show a reduction in close proximity to the tree hedgerow and an increase at 12 m and in the middle of the alleys in comparison with the adjacent reference crop field (Figure 3A). Significant differences were present between the mean yields in the five sampling points and that at the reference site for the 96 m ($p = 0.026$) and 48 m ($p = 0.004$) alleys. No significant differences among the sampling locations and the reference site were measured for the 24 m alley ($p = 0.297$). Multiple comparisons compared each sample location within the crop alley with the reference field (Dunnett's); significant differences were only found between the 48-W-12 and the reference site ($p = 0.006$).

The dry weight of the leaves tended to show a similar pattern to that for yield. The dry weight of the leaves of the sugar beet crop within the alley cropping system tended to be lower than that at the reference site, except for "48-W-12" treatment within the 48 m alley (Figure 3B). Significant differences for dry weight of the leaves were present among all sampling locations in the crop alley and at the control site for the 48 m alley (p=0.02). No significant differences were present for the 96 and 24 m alleys, p = 0.082 and p = 0.119 respectively. A multiple comparisons test comparing each sample location within the 48 m crop alley with the reference site (Dunnett's) showed no significant differences.

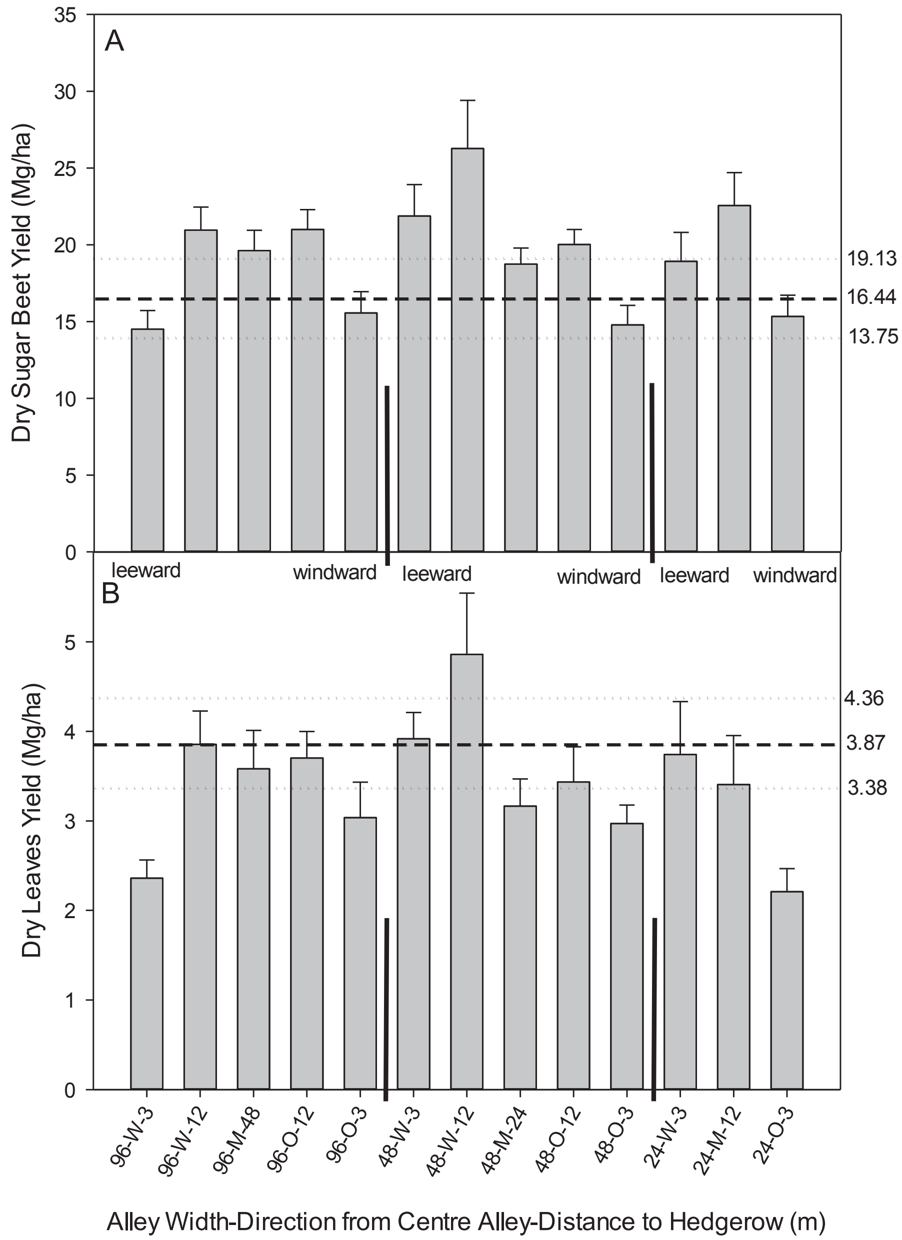


Figure 3. A) Dry sugar beet yields ± SE and B) dry leaf yields ± SE for the different alley widths (96 m, 48 m, 24 m) for the Alley Cropping Research Trial for 2015 (n = 6). *(The horizontal dashed lines in both graphs are the mean of the reference site and the dotted lines indicate the SE of the mean).*

Effect of drought on sugar beet

Drought stressed sugar beets showed significantly smaller diameters with average values of 8 cm compared with 12 cm for non-stressed sugar beets (p = 0.015), and narrower cambium rings of 1.0 mm compared with 1.2 mm (p = 0.041) (Figure 4). The number of cambium rings was also slightly less for drought stressed sugar beets with 9 compared to 10, but this was not significant (p=0.056). Sugar content did not show a significant difference between drought stressed and non-stressed sugar beets with a value around 72% (p = 0.103).

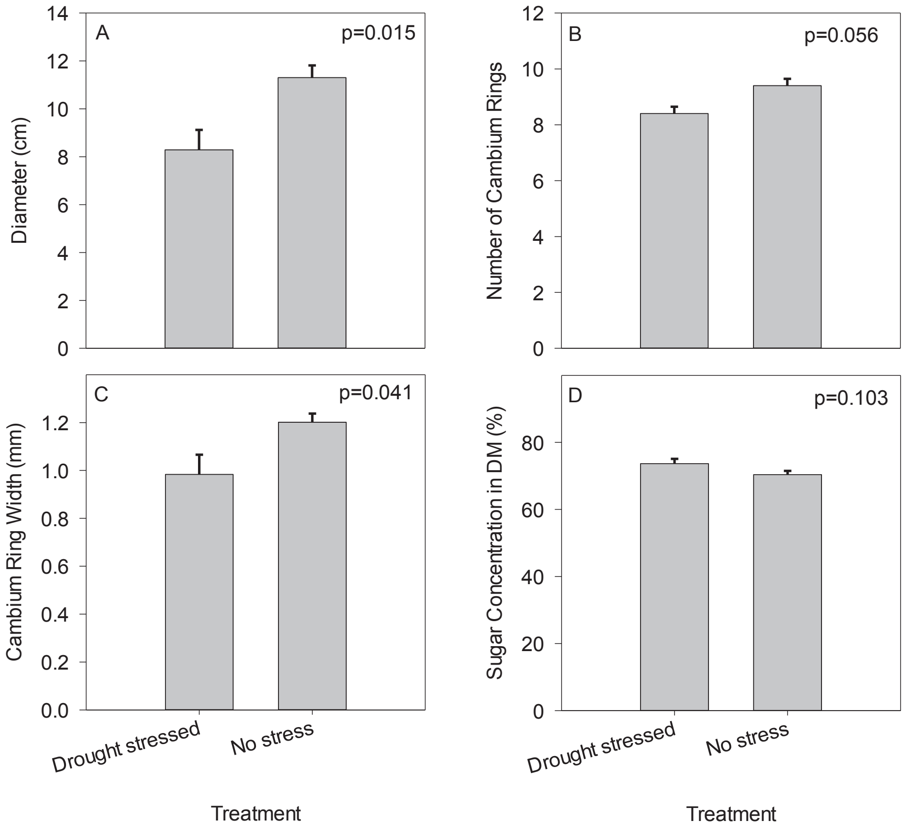


Figure 4. Different drought stress indicators ± SE for sugar beets: A) diameter of sugar beet, B) number of cambium rings, C) cambium ring width, and D) sugar concentration dry matter for the Alley Cropping Research Trial for 2015. *(Samples were taken from the 96 m alley from locations where the sugar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

Discussion and Conclusions

The tree and crop components of agroforestry systems can compete for light, water and nutrients.

During hot and dry summers, the competition for water is likely to be particularly strong. The soils at the Neu Sacro study site are loamy sands (which typically have a low available water content) and hence crops in such soils during dry periods may be predicted to suffer from drought stress and reduced leaf expansion (Bloch & Hoffmann 2005). However the presence of a high water table in most years helps to reduce some of the drought impacts. The 2015 growing season was drier than an average year, especially in May and August (Figure 2), and hence discoloration of the sugar beet leaves was observed before the end of June 2015.

Rao et al. (1998) reported that alley cropping systems can have both positive and negative effects on arable crop water availability in dry years. The provision of shelter (and shading) can reduce temperatures and evapotranspiration rates. However the trees can also compete for water and intercept rainfall. Our data (Figure 2) provides some evidence that rainfall receipts in the 24 m and 48 m alleys was lower than in the reference and 96 m alley for June and July 2015.

At the research site, the hedgerows were harvested in February 2015. Regrowth of the hedgerows from the stools started in May and maximum wind speed data showed (data not shown) that wind speed was reduced by the hedgerows from the middle of June onward. This means that during their establishment phase in May the hedgerow may have had minimal effect on the sugar beet. However during the dry spell in August, there was increased opportunity for tree-crop interactions particularly in terms of water competition. For example Gruenewald et al. (2009) reported lower soil moisture values at a distance of less than 4 m from a hedgerow. Our own data showed this trend to be strongest at the windward side (dominant winds came from the west), where wind sheltering was lower (Mirck et al., 2016).

The lower water availability in close proximity to the hedgerow was associated with low sugar beet yields at a distance of 3 m from the hedgerow (Figure 3). By contrast the higher yields often found at a distance of 12 m or greater from the hedgerow could be associated with changes in soil and air temperature and evapotranspiration (especially on the leeward side due to wind sheltering) (Gruenewald et al., 2009; Boehm et al., 2014). Mirck et al. (2016) reported higher soil moisture values on the leeward side of the hedgerow on 27 July 2015. The soil moisture content was also high on the leeward side of the 48m alley, where a high sugar beet yield was found at a distance of 12 m (Mirck et al., 2016).

Our annual sugar beet yields of 15-25 Mg ha^{-1} are comparable with non-irrigated and irrigated yields of 11-12 Mg ha^{-1} and 16-20 Mg ha^{-1} respectively in northern Germany (Bloch & Hoffmann 2005). Our leaf biomass values of 2.4 - 4.9 Mg ha^{-1} tended to be lower than the values of 5 Mg ha^{-1} and 6-9 Mg ha^{-1} for unirrigated and irrigated sugar beet respectively in northern Germany (Bloch & Hoffmann 2005). This difference between root and leaf yields also resulted in greater root:shoot ratios compared with the Bloch and Hoffmann (2005) study (data not shown).

Growth reductions due to drought stress can be explained in alterations of the root in growth and storage capacity (Hoffmann et al., 2010). The width and number of cambium rings and total root diameter have been used as growth indicators, in addition sucrose concentration has shown a positive correlation with these indicators (Hoffmann et al., 2010). The significantly smaller diameters for the drought-stressed sugar beets and their smaller cambium widths agreed with results for sugar beets grown under three different water capacities reported by Hoffmann et al. (2010). The sugar concentration in our experiment was the same for both stressed and non-stressed sugar beets, which can be explained through the results of Hoffmann et al. (2010). Hoffmann et al. (2010) reported greater sucrose concentrations under non-stressed conditions compared to stressed conditions for *wide rings*, but lower sucrose levels under non-stressed compared to stressed conditions for *narrow rings* (Hoffmann et al., 2010). This could have resulted in an average sugar concentration of wide and narrow rings to be the same for stressed and non-stressed beets.

Acknowledgements
Money for this research was provided though the AGFORWARD project (Grant Agreement N° 613520) which is co-funded by the European Commission, Directorate General for Research

& Innovation, within the 7th Framework Programme of RTD, Theme 2 - Biotechnologies, Agriculture & Food. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission. In addition, Jaconette Mirck also received money through the BRAIN Marie Curie Co-Fund Programme of the European Union.

References

Bloch, B., & Hoffmann, C.M. (2005). Seasonal development of genotypic differences in sugar beet (*Beta vulgaris L.)* and their interaction with water supply. Journal of Agronomy and Crop Science 191: 263-272.

Bloch, B., Hoffmann, C.M., & Maerlaender, B. (2006). Solute accumulation as a cause for quality losses in sugar beet submitted to continuous and temporary drought stress. Journal of Agronomy and Crop Science 192: 17-24.

Boehm, C., Kanzler, M., & Freese, D. (2014). Wind speed reductions as influenced by woody hedgerows grown for biomass in short rotation alley cropping systems in Germany. Agroforestry Systems 88: 579–591.

Boehm, C., Kanzler, M., Mirck, J., & Freese, D. (2015). Effekte agroforstlicher Wirtschaftsweisen auf die Grundwasserqualität von Ackerstandorten. Mitt. Ges. Pflanzenbauwiss 27: 83–84.

Burgess, P.J., Stephens, W., Anderson, G., & Durston, J. (1996). Water use by a poplar-wheat agroforestry system. Aspects of Applied Biology 44: 129-136.

Grünewald, H., Böhm, C., Bärwolff, M., Wöllecke, J., Quinkenstein, A., & Hoffmann, J. (2009). Ökologische Aspekte von Agroforstsystemen. Symposium Energiepflanzen 2009: 233-263.

Hoffmann, C.M. (2010). Sucrose accumulation in sugar beet under drought stress. Journal of Agronomy and Crop Science 196: 243-252.

Monteith, L., Ong, C.K., & Corlett, J.E. (1991). Microclimate interactions in agroforestry systems. Forest Ecology and Management 45: 31-45.

Mirck, J., Kanzler, M., Boehm, C., & Freese, D. (2016). Sugar beet yields and soil moisture measurements in an alley cropping system. Proceedings of the Third European Agroforestry Conference. Montpellier, France 23-25 May 2016.

Quinkenstein, A., Wöllecke, J., Böhm, C., Grünewald, H., Freese, D., Schneider, B.U., & Hüttl, R.F. (2009). Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. Environmental Science and Policy 12: 1112-1121.

Rao, M.R., & Coe, R.D. (1991). Measuring crop yield in on-farm agroforestry studies. Agroforestry Systems 15: 275-289.

Rao, M.R., Nair, P.K.R., & Ong, C.K. (1998). Biophysical interactions in tropical agroforestry systems. Agroforestry Systems 38: 3-50.

United States Department of Agriculture (USDA) (2011). USDA Agroforestry Strategic Framework, Fiscal Year 2011-2016.
http://www.usda.gov/wps/portal/usda/usdahome?navid=FOREST_FORESTRY

Alley coppice: an evaluation of integrating short rotation coppice and timber trees

Paris, P.[1], Nahm, M.[2], Dupraz, C.[3], Morhart, C [2]., Tosi, L.[1], Douglas, G.C.[4], Facciotto, G.[1], Bergante, S.[1], André, J.[3], Lunny, R.[4], Graves, A.R.[5] and Burgess, P.J.[5]

[1] *Consiglio Nazionale della Ricerca - Istituto di Biologia Agroambientale e Forestale (CNR-IBAF), Italy*

[2] *Institute for Forest Growth (IWW), University of Freiburg, Germany*

[3] *Institute National de la Recherche Agronomique (INRA), France*

[4] *Teagasc, Kinsealy Research Centre, Dublin, Ireland*

[5] *Cranfield University, UK*

Abstract: This paper summarises the main results from a recent research project focused on an innovative Alley Coppice (AC) land use system. We report on an AC system comprising standard trees for the production of valuable wood and the alley intercropping of short rotation coppice trees (SRC) for the production of bioenergy. Much of this work was carried out within the European project AgroCop (2012-2014) that combined field experimentation with bio-economic modelling. Two experimental plantations are located in Italy and France. The first plantation (9 years old) was used to study the intercropping of *Pyrus* spp. and *Sorbus* spp., as standard trees, with poplar SRC. Current measurements do not show any difference in stem height between intercropped standard trees and trees in pure plantation forestry. This was probably due to shading by the SRC canopy on standard trees. Nevertheless, this light competition has improved the stem form of standard trees, with a main bole almost straight and free of defects. In France, the poplar SRC crop was established into the alleys of a hybrid walnut tree plantation (18 years old) in a system we term: delayed alley coppice. Poplar growth was strongly limited by the shade of the walnut trees, although some microclimatic mitigation of water stress was observed on poplar shoots during the peak of summer heat. Biophysical modelling was conducted with the calculation tool YDEAL, comparing AC (hybrid walnut intercropped with poplar SRC) vs SRC monoculture vs walnut forestry monoculture. Simulations were performed on a 60 year rotation cycle of AC (harvesting cycle for the standard trees), and three cycles of 20 years for the poplar SRC, with triennial coppicing. Three growth condition scenarios were studied, namely poor, medium and optimum site conditions, mostly according to average yield data of poplar SRC (6, 10 and 15 t dry matter ha^{-1} $year^{-1}$, respectively). The financial analysis was performed using a calculation tool named FinAC. The AC system could be as profitable as the forestry monoculture, in the best financial and environmental scenarios, with the wood price determining absolute system profitability. AC can provide a landowner with a periodical annual income during the growth of standard trees. The feasibility of AC is partly limited by wood market uncertainty, the use of farmland for a medium-long period with the same culture, and the current difficulty in estimating AC profitability. AC could be used as a temporary system (10-15 years) to improve the stem form and wood quality of standard trees.

Keywords: AgroCop project, alley coppice, agroforestry, biomass, LER, NPV

Introduction

A bio-based economy, which produces sources of renewable energy and raw materials, requires land use systems which combine the production of food, feed and wood with environmental safeguards to mitigate global warming and greenhouse gas (GHG) concentration in the atmosphere. The use of wood, as timber but also as a source of energy, provides one option to help reduce the use of fossil fuels. Yet, current trends indicate that the demand for woody biomass will exceed its supply. Therefore there is interest in Europe in new land use concepts that will facilitate both timber and biomass production in a sustainable and economically viable way. Agroforestry and short rotation coppice (SRC), for timber and bioenergy wood production, are two such systems.

Agroforestry is the deliberate combination of agricultural activities (crops and/or livestock) with trees. It can be used as an alternative to plantation forestry for timber production, using tree species which can produce valuable hardwood timber such as walnut (*Juglans* spp.) and cherry (*Prunus avium*) (Graves et al., 2007; Palma et al., 2007). Agroforestry can increase land productivity by the complementary capture of light, water and nutrients by the different tree and crop components. One way of measuring the improvement in land productivity is to use the Land Equivalent Ratio (LER) (Mead & Willey, 1980). LER compares the yields from growing two or more crops together with the yield obtainable from growing the same crops in monocultures or pure stands. When the LER is higher than one, the intercropping is more productive than monocultures because of beneficial interactions. For agroforestry systems combining timber trees and crops in Europe, LER simulations varied between 1.0 and 1.4 (Graves et al., 2007).

Short rotation coppice (SRC) can produce wood biomass within short cycles (2-5 years) using densely-planted fast-growing trees (e.g. poplars, willows, eucalypts (*Eucalyptus* spp.), robinia (*Robinia pseudoacacia*)) with coppicing ability. Cultural operations, from planting to wood harvesting are all mechanised (Vanbeveren et al., 2015), with minimum requirement of manual labour, similar to herbaceous crops (Morhart, 2013; Paris et al., 2011; 2015). The coppicing cycles of 2-5 years vary according to site conditions and species (Facciotto et al., 2015). A new tree-based intercropping system (Figure 1) using an agroforestry approach with SRC, called alley coppice (AC) (Morhart et al., 2014), was investigated in the European research project AgroCop (www.agrocop.com).

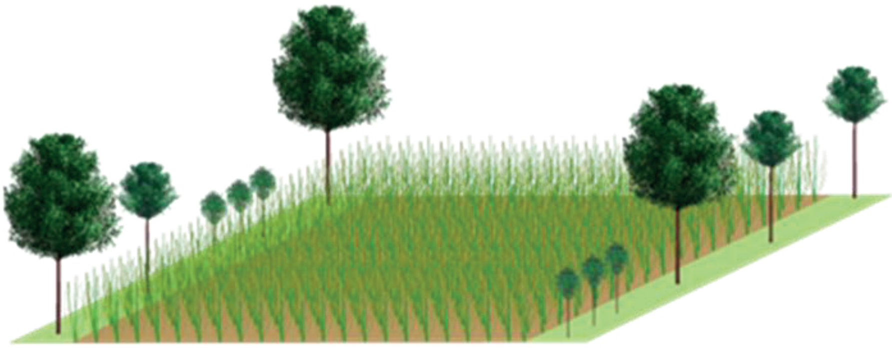


Figure 1. Alley coppice plot, combining timber trees planted at a regular wide pattern with short rotation woody crop (SRC) of densely panted fast growing trees in wide alleys with coppice management *(from Morhart et al., 2014).*

We started from the hypothesis that AC has important potential advantages including: i) a regular income guaranteed from the SRC component; ii) a land equivalent ratio (LER) potentially greater than 1.0; iii) improved stem form of timber trees due to little competition between the species and intensive tree management; vi) reduced costs because timber trees can be planted at their final spacing, avoiding expensive thinning operations; v) reduced wind/storm damage to young timber trees because the SRC component protects young timber trees, and vi) positive impacts on biodiversity and reduced soil erosion. The aim of this paper is to present an updated synthesis of the main results obtained from the research activity carried out in Europe regarding alley coppice, combining data from experimental plots, and biophysical and financial modelling.

Experimental plots and results

New AC systems were established in France, Germany, Italy and Ireland in the last decade. In this document, we report some of the results that were obtained from two sites, where we assessed different planting scenarios beginning with two different establishment methods: 1) Simultaneous planting (SP) where valuable timber trees and SRC were planted at the same time (site in Italy); and 2) Delayed planting (DP) where SRC was planted between already existing rows of valuable timber trees. On these experimental sites, the growth and yield of timber and SRC trees were studied, and competitive interactions for light and water resources were monitored using hemispherical photography and measurements of plant water potentials.

Simultaneous planting

In Italy, the study site was located near the city of *Casale Monferrato* (45°08’ N; 8°30” E, 102 m a.s.l.) in Northern Italy. The SP experimental field, with a total area of 1.5 ha, was established by CRA-PLF in 2007 on flat agricultural field with alluvial soil. The climate of the area, according to Köppen-Geiger world climate classification, is warm, temperate, fully humid, with hot/warm summers. The soil texture is sand and sandy loam. Experimental plots were established for comparing pure plantations of *Sorbus domestica* L. and *Pyrus comunis* L. (3 clones) with a mixture of the same trees and poplar clones under biennial SRC harvests in an AC system, using a randomised block design with two replications. Poplars were planted using 120 cm long unrooted stem cuttings, placed horizontally on the soil surface with an inter-row distance of 2 m. Timber trees were planted at 8 m x 8 m spacing. The distance between the trees and the poplar SRC is 3 m. Since the establishment year, tree growth and yield have been recorded.

The timber tree species in alley coppice stands showed a steady growth, reaching a mean height of 438 and 395 cm for *Pyrus* and *Sorbus* respectively (Figure 2), while the maximum height which was obtained in the pure stands was 523 cm for *Pyrus* and 453 cm for *Sorbus* (data not shown). Timber trees in the AC treatment suffered light competition (see Paris et al., 2014) from the SRC poplar whose height was cyclically dominating the timber trees during the first 6 years, with 3 biennial harvests by coppicing. On the other hand, light competition positively affected the wood quality, as demonstrated by the value of the index of wood quality (*Q*) (Paris et al., 2014), measured at the end of the seventh growing season, which was higher for plants grown in combination with SRC poplar (55) than for those grown in pure stands (32). The competition improved the stem shape and forced the high-value timber trees to grow with a straight stem and thinner branches (Paris et al., 2014). From the seventh season, the height of the timber trees was greater than the poplar SRC which should minimise further light competition from the SRC.

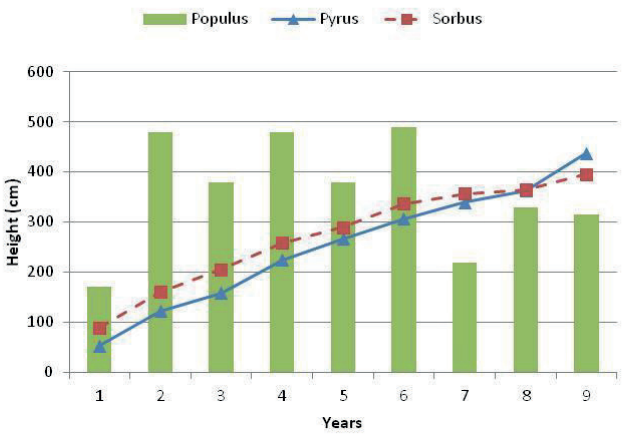


Figure 2. Simultaneous AC system. Total height of high-value timber trees (*Sorbus* and *Pyrus*) and SRC poplar in the alley coppice experimental field, with biennial coppicing rotation (harvests in years 2, 4, 6, 8) for the first nine years since establishment (Casale M., Italy) *(Facciotto et al., 2016).*

Delayed planting
The DP site was located close to Montpellier (43°43'07'"N; 3°54'29'E, 117 m a.s.l.) in Southern France. It had a total area of 1.5 ha. The climate of the area is temperate, Mediterranean with dry and hot summers (Köppen-Geiger). The soil is alluvial, its texture is loamy clay sand. Hybrid walnut (*Juglans regia x nigra* L.) timber trees were planted in 1995, in an alley cropping system design with a 13 m x 8 m spacing. Winter cereals were the principal crops in the initial years. Poplar cuttings (variety Monviso) were planted in 2012 in double rows (10,000 trees ha^{-1}) between the 18-year-old timber tree lines at a distance of 2 m from them. A SRC control without timber trees was also planted. A randomised block design with three replicates was used. Tree growth, yields, understory illumination, and poplar water status (via mid-day and pre-dawn leaf water potential, Ψ_{md} and Ψ_{pd}, respectively) conditions were studied during the year 2013.

The first coppicing rotation gave a very low yield both in the pure SRC system (without hardwood trees) and in AC, 1.0 and 0.3 Mg dry matter ha^{-1} $year^{-1}$, respectively. In 2014 the SRC yields in the AC were less than 40% of that in the pure SRC (Figure 3). There was a strong competition gradient from the timber tree line to the centre of the intercrop alley, with yields at 2 m being significantly less than those at 6 m. A significantly higher water stress on poplar was measured in the presence of timber trees, with water stress on poplar shoots increasing the closer they were to the walnut row. However, this competition for water was mitigated by the microclimatic effect of timber trees. Indeed, we observed a protection effect by walnut shade on SRC, by measuring differences between Ψ_{md} and Ψ_{pd} in control and AC. This may explain the yield difference between north and south SRC exposure (André et al., 2015).

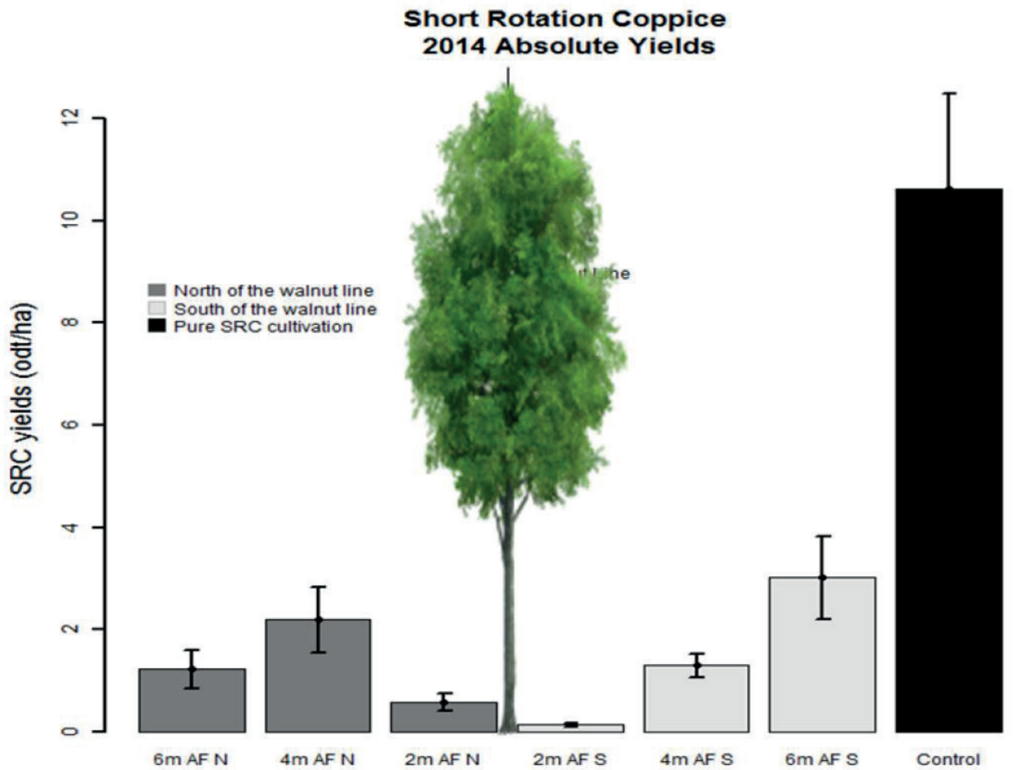


Figure 3. SRC yields in a Delayed Alley Coppice System. SRC poplar yields depending on sun exposure (south (S) and north (N) sides) and distance from timber tree line (2, 4 and 6 m) (Montpellier, France) *(André et al., 2015)* and yields from pure SRC without hardwood trees.

Biophysical modelling

Within the AgroCop project, a calculation tool was developed for assessing the biophysical behaviour of AC systems. This tool, called YDEAL (Yield Dynamics Estimation for Alley Coppice), describes the yield dynamics for AC systems under defined conditions or scenarios, based on a meta-analysis of available literature data and on data measured directly on the project's field sites. We assessed different scenarios, beginning with the two different establishment methods, *simultaneous planting* and *delayed planting*. In the simulations, we considered hybrid walnut as the timber tree and hybrid poplar for the SRC crop. The two AC methods were applied for three different growth scenarios, namely poor, average and optimum growth conditions (by meta-analysis). In the poor scenario, for sub-marginal site conditions, we assumed for the SRC a potential yield of 6 t ha^{-1} $year^{-1}$ of dry woody biomass (or dry matter, dm) and 1.6 m^3 of timber per tree for walnut. In the average scenario, the SRC has a yield of 10 t dm ha^{-1} $year^{-1}$ and walnut has a timber yield of 1.1 m^3 $tree^{-1}$. In the optimum scenario, SRC has a yield of 15 t dm ha^{-1} $year^{-1}$ and walnut has a yield of 1.6 m^3 $tree^{-1}$. Major details on the biophysical modelling are reported in André et al. (2015). Output examples of YDEAL simulations are shown in Figure 4.

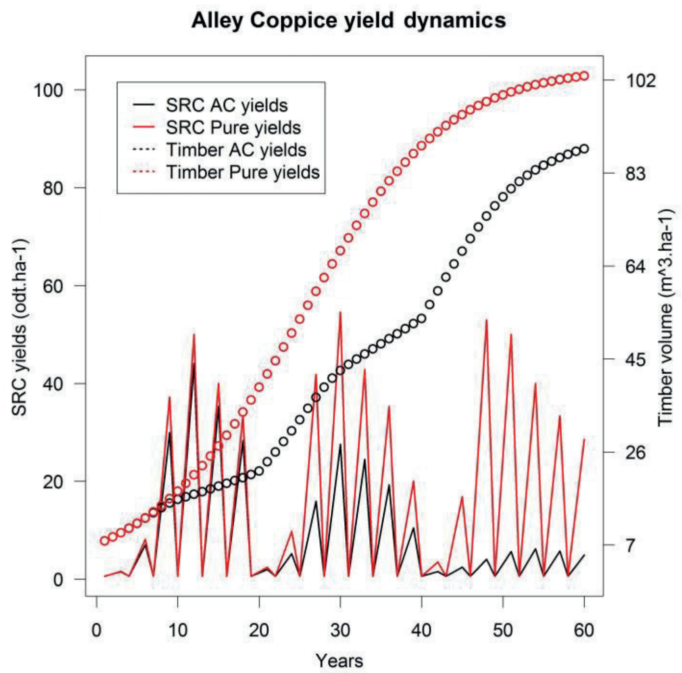


Figure 4. Output examples of the biophysical model YDEAL developed in the AgroCop project for Alley Coppice (AC) systems, with simultaneous planting method under the scenario of optimum growth conditions (fertile alluvial soil of Central-western Europe), with hybrid walnut as timber tree and hybrid poplars as SRC species

In the simultaneous AC scenario, the growth of timber trees in the AC system was less than in the pure timber system during the first 20 years due to light and water competition. In the following two SRC cycles of 20 years, the timber trees became more competitive for light and perhaps soil water resources. In the delayed planting methods (not shown), during the first 20 years the growth of timber trees is unaffected, because there is no competing intercrop. In the following two SRC cycles of 20 years, both the timber trees and SRC crop have reduced yields in comparison to their respective monocultures. The simulations shown in Figure 4 for the optimum scenarios were also run for the poor and average scenarios (data not shown), obtaining yield data for all the studied scenarios. These data were used to calculate the LER of AC in the different scenarios (Table 1), which was always higher than one.

Table 1. Modelled values of LER (Land Equivalent Ratio) of Alley Coppice systems (AC) under different growth scenarios and establishment methods (simultaneous and delayed planting)

	Growth scenarios		
	Poor	Average	Optimum
Simultaneous planting of SRC	1.10	1.13	1.22
Delayed planting of SRC	1.05	1.07	1.13

Financial modelling

To determine the financial profitability of AC systems for farmers and landowners, a specific calculation tool (FinAC; Tosi, 2015) was developed, with a specific database containing all the costs of cultural operations and cultural inputs for timber plantation forestry and for SRC.

These data were derived by using information from the countries involved in the AgroCop project (Germany, Ireland, Italy and France). These costs were then standardised, in order to find a modelling condition with representative values of average conditions of Western Europe. Market values of wood biomass for energy and timber were standardised to average values of 70 € (t dm)$^{-1}$ and 500 € m^{-3}, respectively, although these values can be strongly variable in time and on local or regional markets. A discount rate of 3.5% (year 1-30) and 3.0% (year 31-60) was assumed. Financial simulations were then run using the yield outputs of YDEAL, for the above mentioned growth scenarios.

Under the poor scenario, the NPV values are very low, equivalent to 630 € ha^{-1} for the poplar SRC and 290 € ha^{-1} for the simultaneous Alley Coppice (Figure 5). Forestry gave a NPV of 3,700 € ha^{-1}. For the Alley Coppice, both lagged and simultaneous, in the last 20 years of the cycle it would not be possible to cultivate SRC poplars because of strong competition, mostly for light, by the adult walnut trees. Given the low productivity of the SRC, the NPV of the delayed AC (1,680 € ha^{-1}) was higher than the simultaneous planting because of the reduced costs for plant material, establishment and management during the first 20 years.

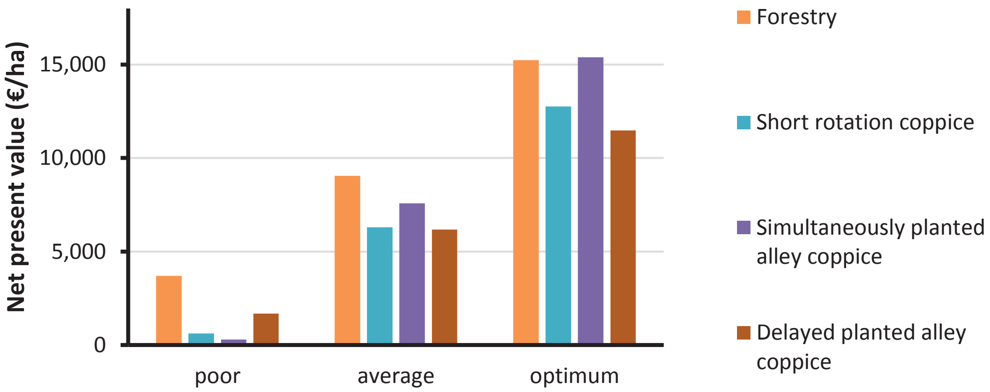


Figure 5. Output example of the economic model (FinAC) developed in AgroCop, displaying the Net Present Value (NPV) (€/ha) of alley coppice systems grown in different scenarios with average, poor and optimum growth conditions. For the simulation we assumed a 60 years plantation with replacement of SRC trees each 20 years. The harvesting cycle of SRC is triennial. We selected walnut as the timber tree and poplar as SRC woody crop.

In the average scenario, the highest NPV was again achieved from forestry (9,057 € ha^{-1}), although the alley coppice systems increased in relative profitability. In the optimum scenario, the best NPVs were achieved by forestry (15,240 € ha^{-1}) and the simultaneous alley coppice system (15,380 € ha^{-1}) (Figure 5). In conclusion, the forestry system was generally more profitable at the end of the 60 years' cycle in comparison to AC and pure SRC. However forestry has only a final return after 60 years, without any intermediate income, other than the final sale of the valuable timber (except for the small income coming from thinning operations). Under the optimum and average scenarios, simultaneous AC provided a higher NPV than SRC culture. Hence, in comparison to the more profitable Forestry, AC guarantees an income every three years thanks to the harvest and selling of biomass from intercropped SRC; in comparison to SRC monoculture, alley coppice guarantees a slighter higher profitability, with the final income from the timber harvest and selling.

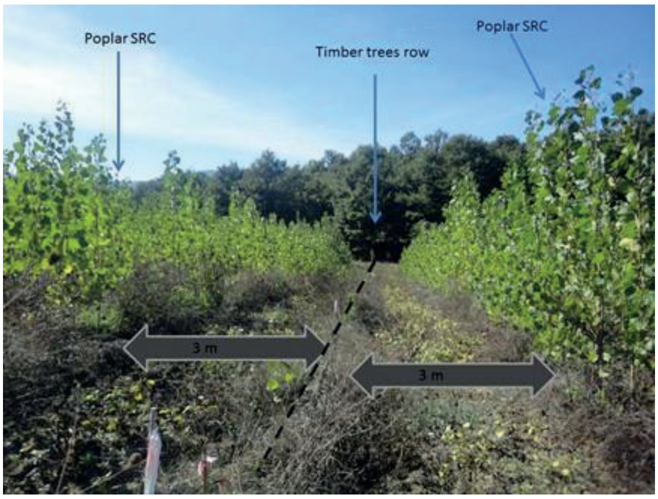


Figure 6. La Valletta, Italy (42°40'55"N; 12°23'26''E). A 10 ha commercial poplar SRC plantation where few rows of poplar were removed after one year and planted with wild cherry (*Prunus avium*) seedlings in spring 2013. This activity was carried out within the Agrocop project. Planting some timber tree lines when establishing an SRC plantation can be a feasible way of integrating timber and bioenergy production. Once the timber trees have reached a good size it may be possible to remove the SRC stools (approx. after 10-15 years) so that the alleys can be intercropped with annual crops.

Discussion and Conclusions

The study indicates that the Alley Coppice system represents an interesting opportunity to integrate timber and bioenergy production, with synergic benefits in terms of stem form of timber trees and a LER > 1.0. However the financial analysis suggests that AC shows the highest relative and absolute profitability under favourable growth conditions. In general the walnut monoculture for timber production gave the highest profit. These results should be used with caution because of the limitations of the modelling approach and because the productivity and quality of forestry based on monocultures can be very variable. For example, the last 25 years in Italy have seen many failed attempts to convert marginal agricultural lands to monoculture hardwood plantations for timber production using European grants (Facciotto et al. 2015). Our models (YDEAL (André et al. 2015); FinAC (Tosi, 2015)) are based on a preliminary and a relatively small data set. It is desirable to collect more field data to generate a more reliable database to improve our prediction of the biophysical and economic behaviour of alley coppice systems. The achievement of high yields of high quality timber depends on the appropriate choice of planting materials and tree management experience, and the returns are very sensitive to unreliable timber prices.

The agroforestry system is an alternative method for establishing valuable broadleaved species for timber production on good fertile soils whilst producing other crops within the tree rotation. In Europe, the Common Agricultural Policy (CAP) offers the potential for national governments to support the establishment of agroforestry systems and SRC plantations. Depending on the initial assumptions, AC systems might be more profitable than SRC monocultures in medium and good site conditions. Therefore we recommend that, for new SRC plantations, consideration should be given to planting several rows of timber trees in combination with wide alleys (at least 25-30 m) of SRC crops (Figure 6). The experimental work suggests that alley coppice systems can also improve the stem form and thereby the potential timber quality of valuable tree species like walnut and wild cherry (Loewe et al., 2013; Mohni et al., 2009).

Acknowledgements

Much of the data provided in this paper were collected within the European research project AGROCOP, funded by a joint WOODWISDOM and ERANET programme. Manuscript preparation was supported by AGFORWARD project (Grant Agreement N° 613520) which is co-funded by the European Commission within the 7th Framework Programme. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

References

André J., Dufour L., Le Bec J., & Dupraz, C. (2015). Project AgroCop Report.

El Kasmioui, O., & Ceulemans, R. (2012). Financial analysis of the cultivation of poplar and willow for bioenergy. Biomass and Bioenergy 43: 52-64.

Facciotto, G., Minotta, G., Paris, P., & Pelleri, F. (2015). Tree farming, agroforestry and the new green revolution; a necessary alliance. In: O Ciancio (Ed.) Proc. II Inter Congress Silviculture, Vol. II, 658-669. Italian Academy of Forest Sciences, Firenze, Italy, 26-28 Nov. 2014

Facciotto, G., Paris, P., & Bergante, S. (2016). Growth and yield results of timber trees mixed with poplar SRC: 9 years of an experimental plot in the Po Valley. Proceedings of the 3rd EURAF Conference on Agroforestry.

Graves, A.R., Burgess, P.J., Palma, J.H.N., Herzog, F., Moreno, G., Bertomeu, M., Dupraz, C., Liagre, F., Keesman, K., van der Werf, W., Koeffeman de Nooy, A., & van den Briel, J.P. (2007). Development and application of bio-economic modelling to compare silvoarable, arable and forestry systems in three European countries. Ecological Engineering 29: 434-449.

Loewe, V.M., González, M.O., & Balzarini, M. (2013). Wild cherry tree (*Prunus avium L.*) growth in pure and 747 mixed plantations in South America. Forest Ecology and Management 306: 31-41.

Mead, R., & Willey R.W. (1980). The concept of a 'land equivalent ratio' and advantages in yields from intercropping. Experimental Agriculture 16: 217-228.

Mohni, C., Pelleri, F., & Hemery, G.E. (2009). The modern silviculture of *Juglans regia L.*: a literature review. Bodenkulture 60(3): 21-34.

Morhart, C., Sheppard, J., Seidl, F., & Spiecker, H. (2013). Influence of different tillage systems and weed treatments in the establishment year on the final biomass production of short rotation coppice poplar. Forestry 4: 849-867. doi:10.3390/f4040849.

Morhart, C.D., Douglas, G.C., Dupraz, C., Graves, A.R., Nahm, M., Paris, P., Sauter, U.H., Sheppard, J., & Spiecker, H. (2014). Alley coppice-a new system with ancient roots. Annals of Forest Science 71: 527-542. doi:10.1007/s13595-014-0373-5

Palma, J.H.N., Graves, A.R., Bunce, R.G.H., Burgess, P.J., de Filippi, R., Keesman, K.J., van Keulen, H., Liagre, F., Mayus, M., Moreno, M., Reisner Y., & Herzog F. (2007). Modelling environmental benefits of silvoarable agroforestry in Europe. Agriculture, Ecosystems and Environmen, 119: 320-334.

Paris, P., Bergante, S., Tosi, L., Minotta, G., Biason, M., Ventura, M., & Facciotto, G. (2014). Innovative alley coppice systems - mixing timber and bioenergy woody crops: 7 years' growth and ecophysiological results in experimental plots in northern Italy, Po Valley. Proceedings of 11th European IFSA Symposium, Farming Systems Facing Global Challenges, Berlin, April 2014.

Paris, P., Mareschi, L., Sabatti, M., Pisanelli, A., Ecosse, A., Nardin, F., & Scarascia-Mugnozza, G. (2011). Comparing hybrid *Populus* clones for SRF across northern Italy after two biennial rotations: Survival, growth and yield. Biomass and Bioenergy 35: 1524-1532. doi:10.1016/j.biombioe.2010.12.050

Paris, P., Mareschi, L., Sabatti, M., Tosi, L., & Scarascia-Mugnozza, G. (2015). Nitrogen removal and its determinants in hybrid *Populus* clones for bioenergy plantations after two biennial rotations in two temperate sites in northern Italy. iForest Biogeosciences and Forestry 8: 668-676. doi: 10.3832/ifor1254-007.

Tosi L. (2015). Analisi sperimentale, produttiva e finanziaria dell'arboricoltura multifunzionale da biomasse e legname pregiato (Alley Coppice). PhD Thesis, Università degli Studi della Tuscia, Viterbo.

Vanbeveren S.P.P., Schweier J., Berhongaray B., &, Ceulemans, R. (2015). Operational short rotation woody crop plantations: manual or mechanised harvesting? Biomass and Bioenergy 72: 8-18.

Silvoarable agroforestry: an alternative approach to apple production?

Smith, J.[1], Crossland, E.M.[1] and Wolfe, M.S.[2]

[1]*The Organic Research Centre, Hamstead Marshall, UK*

[2]*The Organic Research Centre, Wakelyns Agroforestry, Suffolk, UK*

Abstract: Novel land use systems that integrate woody species into the agricultural landscape have the potential to balance productivity with protection of the environment and the maintenance of ecosystem services. Integrating top fruit production into an agroforestry system, where woody species are integrated with arable crop production, may have a beneficial effect on the control of plant pathogens such as apple scab (*Venturia inaequalis*). However, the introduction of such systems into European high-yielding traditional apple production systems will meet substantial obstacles as the approach affects not only agronomic performance but also well-established fruit production traditions. This paper reports on research that evaluated an apple-arable agroforestry approach as a sustainable strategy for reducing copper inputs in organic and low input systems using two contrasting case studies; Wakelyns Agroforestry in Suffolk and Whitehall Farm, Cambridgeshire. The results presented here focus on three elements that are likely to be impacted by an agroforestry systems approach to apple production: (i) yield and quality of apples; (ii) emergence of primary and secondary pests and diseases; and (iii) impact on management activities. Potential synergies and tensions are identified and discussed.

Keywords: *Venturia inaequalis,* alley cropping, organic

Introduction

Novel land use systems that integrate woody species into the agricultural landscape have the potential to balance productivity with protection of the environment and the maintenance of ecosystem services (Jose, 2009). An emphasis on managing rather than reducing complexity promotes a functionally biodiverse system with both ecological and economic interactions between trees and crops and livestock (Lundgren, 1982). Although the potential of agroforestry-based agricultural systems has been demonstrated in principle (Quinkenstein et al., 2009), information on their usefulness in the context of European low-input production systems is lacking. Also, the introduction of such systems into high-yielding traditional European apple production systems will meet substantial obstacles as the approach affects not only agronomic performance but also well-established fruit production traditions. As part of the European FP7-funded project 'Innovative strategies for copper-free low-input and organic farming systems (CO-FREE, www.co-free.eu)', we have been evaluating an innovative apple/arable agroforestry system as a potentially sustainable strategy for reducing copper inputs in organic and low input systems. The aim is to provide information on the potential of agroforestry in the European context.

Integrating top fruit production into an agroforestry system, where woody species are integrated with crop production, may have a beneficial effect on the control of plant pathogens such as scab (*Venturia inaequalis*) due to a number of mechanisms:

(i) A greater distance between tree rows in agroforestry systems, with crops in the adjoining alleys, is likely to reduce the spread of pathogens. This has been recorded for crop pathogens in agroforestry systems (Schroth et al., 1995) but the evidence for tree pathogens is inconsistent (Schroth et al., 2000).

(ii) Lower densities of trees compared with orchards favour increased air circulation which has been shown to reduce the severity of scab by reducing leaf wetness duration (Carisse & Dewdney, 2002).

(iii) Regular cultivations within the crop alleys will incorporate leaf litter into the soil, thus enhancing decomposition and reducing the risk of re-inoculation from overwintered scabbed leaves the following spring.

This research aimed to evaluate an apple-arable agroforestry approach as a sustainable strategy for reducing copper inputs in organic and low input systems using two case studies; Wakelyns Agroforestry, Suffolk, UK and Whitehall Farm, Cambridgeshire, UK. The results presented here focus on three elements that are likely to be impacted by an agroforestry systems approach to apple production: (i) yield and quality of apples; (ii) emergence of primary and secondary pests and diseases; and (iii) impact on management activities.

Methods

Case-study systems

Case Study 1: Wakelyns Agroforestry, an organic silvoarable research site, was established in 1994 on 22.5 ha in eastern England (52.36ºN, 1.36ºE). Within the 2 ha apple-arable agroforestry system, a diverse mix of 21 varieties of apple trees on MM111 rootstock are interspersed with seven timber species, in north/south rows with 12 m-wide crop alleys between adjacent rows. Cereals, potatoes, field vegetables and fertility-building leys are grown in rotation within the alleys. The apple trees cover 2.5% of the land area in the 2 ha system. A local modern 0.6 ha organic orchard acted as a benchmark for comparison.

Research at Wakelyns was carried out in 2012 and 2013. The experimental design at Wakelyns consisted of four plots, each plot including two tree rows and the crop alley in between, with 7-10 apple trees in each plot interspersed with timber trees. At Clarkes Lane Orchard there were also four plots, each plot consisting of two tree rows and the narrow grass alley in between.

Figure 1. Mixed apple and timber tree system at Wakelyn's Agroforestry, Suffolk, UK

Case Study 2: The agroforestry system at Whitehall Farm is more commercial than that at Wakelyns Agroforestry in terms of design and scale. Whitehall Farm is a 100 ha organic arable farm on high quality soil near Peterborough, in eastern England (52.53°N 0.18°W). Previously managed as an intensive arable system, the eastern half of the farm entered into organic conversion in 2007, while the rest entered conversion in August 2009. In October 2009, 4,500 apple trees, consisting of 13 varieties were planted in rows running NE/SW 27 m apart, with 3 m spacing of trees within rows. The understorey was sown before tree planting with a 3 m band of nectar flower mixtures and legumes. The 24 m remaining between rows is cropped on an organic rotation including cereals, vegetables and legume fertility-building leys. Late maturing apple varieties have been chosen to allow harvesting of the alley crops first. Research at Whitehall Farm was carried out in 2014 and 2015. Three apple varieties were chosen for inclusion in the research, based on number of replicated rows available and their degree of scab resistance, to include the susceptible variety Bramley, the moderately resistant variety Falstaff and the resistant variety Red Windsor. For each of the varieties, three rows were sampled, with four assessments per tree and with 100 assessments in total per sample (i.e. 25 trees), and two samples per row (i.e. six samples per variety). There was no local commercial organic orchard to use as a benchmark and so Willock Farm, a local heritage orchard, was used as a comparison. In the orchard, all apple trees were assessed, with four assessments per tree.

Figure 2. Organic apple silvoarable system at Whitehall Farm, Cambridgeshire, UK

Yield and quality of apples

Case Study 1: In autumn 2012 and 2013, all apples harvested from each site were graded as Class I/Class II/processing/waste and weighed per class and variety. The grading followed Commission implementing regulation (EU) No 543/2011 available at www.gov.uk.

Case Study 2: In autumn 2014 and 2015, all apples were harvested at Whitehall Farm by commercial pickers and total yields per variety obtained. As the apples were destined for juicing, just prior to harvest four apples per tree were graded as Class I/Class II/processing/waste to assess quality, with 100 assessments in total per sample, and two samples per row (i.e. six samples per variety).

Pests and diseases

Case study 1: Pests and diseases were assessed in the plots at three points – small fruits in July 2012 and 2013, large fruits in August 2012 and 2013, and the harvested apples (September to November 2012 and 2013). Scab levels and incidences of other pests and diseases in the agroforestry and orchard plots in 2012 and 2013 were compared statistically using t-tests, using R version 2.10.0 (R Development Core Team, 2009). Each sample consisted of 100 plant units chosen randomly from all trees in the plot area (i.e. 100 small developing fruits; 100 large fruits pre-harvest; 100 harvested fruits). Each plant unit was thoroughly inspected for eggs, insects or insect damage and diseases.

Case Study 2: Pests and diseases were assessed in the plots at two points before harvest – small fruits in July 2014 and 2015, and large fruits just prior to harvest in September 2014 and 2015. For each of the three varieties, three rows were sampled, with four assessments per tree and 100 assessments in total per sample, and two samples per row (i.e. six samples per variety). Scab levels and incidences of other pests and diseases in the three variety plots at Whitehall and Willock Farm orchard plots in 2014 and 2015 were compared statistically using one-way ANOVAs with 'treatment' (Bramley, Falstaff, Red Windsor, Orchard) as a fixed factor, using R version 2.10.0 (R Development Core Team, 2009). Where a significant effect was found, *post-hoc* pairwise comparisons of means were performed using Tukey's HSD test to identify significant differences between treatments.

Impact on management activities

To identify the main management benefits and challenges of integrating apple and arable production systems, a case study approach was used. Semi-structured interviews were conducted with key informants from innovative silvoarable apple systems. Four silvoarable apple systems located in East Anglia, the East Midlands and the South West of England were selected as case study sites. Interview methods followed those outlined by Pretty et al. (1995), involved both face-to-face and telephone interviews, and took between 30 and 120 minutes. All interviews were recorded and supported by notes. Questions covered three main themes: (i) motives for establishing silvoarable agroforestry; (ii) observed benefits and challenges in regards to the main management activities of both arable and apple production; and (iii) the future adoption of silvoarable agroforestry within the UK. All interviews were transcribed and interview notes added to the transcripts. Content analysis was used to identify dominant topics and concepts, coding the interviews thematically using the software QDA Miner 4 (Provalis Research, 2015). Further analytical steps followed those outlined by Hennink et al. (2010) and included development of thick descriptions for each topic to explore the context and meaning of each issue, cross-case comparisons to highlight patterns across interviews, grouping codes into meaningful categories and exploring the relationships between these categories.

Results

Yield and quality of apples

Case Study 1: Apple production in England in 2012 was severely affected by heavy rain from April to June and late frosts, with some fruit farmers reporting losses of up to 90% of their crop. In the agroforestry and orchard sites, some varieties failed to set fruit (e.g. Cornish Gillyflower at Wakelyns; Spartan and Winter Gem at Clarkes Lane Orchard), or had very low fruit set. In addition, high levels of scab impacted on yields at the orchard (see below) and so the resulting total apple yields were very low (Figure 3). Yields within the agroforestry were higher; even allowing for the fact that apple trees cover only 2.5% of the area (tree plus understory). Comparing yields with standard figures from the Organic Farm Management Handbook (Lampkin et al., 2014) by calculating the yield of 100% agroforestry apples (i.e. multiplying by 40), the yields from the agroforestry compare favourably with standard yields (Class I & II: 15.7 t/ha from the agroforestry vs. 14 t/ha from orchards at peak production). Apple yields in 2013 were substantially better than in 2012. Yields within the organic orchard were 2.24 t/ha (Class I, II and processing) compared with 0.72 t/ha from the agroforestry (Figure 3) which, when scaled up to 100% apples, again compares favourably with standard figures (Class I & II: 19.25 t/ha from the agroforestry vs. 14 t/ha from orchards at peak production (Lampkin et al., 2014)).

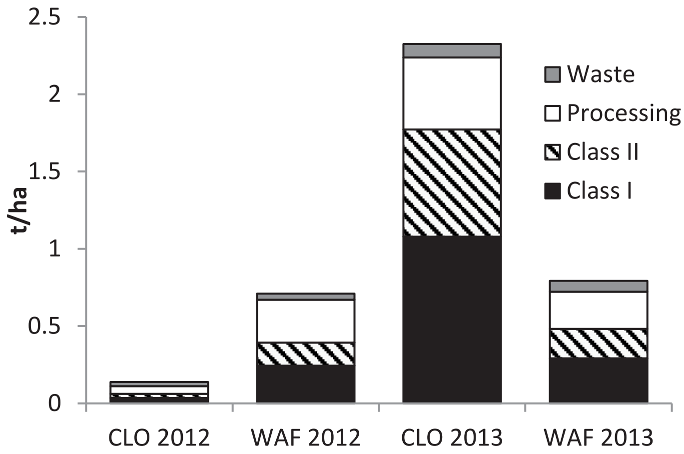


Figure 3. Apple yields (t/ha) from the agroforestry (WAF) and orchard (CLO) sites in 2012 and 2013. NB. Apple trees account for 2.5% of land area in the agroforestry system.

Case Study 2: In the agroforestry system, tree rows account for 10% land area with 85 trees/ha; scaling up to 100% apples, yields in 2014 ranged from 0.25 t/ha to 5.95 t/ha and in 2015 from 1.36 t/ha to 15.18 t/ha (Table 1), which compares with standard yields for 5 year old orchard of 3 t/ha and an organic orchard in peak production (6-11 years) of 14 t/ha (Lampkin et al., 2014). There was a wide range of yields from different varieties and in the two years, with two of the low yielding varieties (Falstaff, Bramley) in the same field, which may indicate problems with pollination or mineral deficiency although these two varieties also had high levels of scab in 2014. There was a higher proportion of processing apples in 2014 compared with 2015 (Figure 4).

Table 1. Yields of apples in the agroforestry system at Whitehall Farm, 2014 and 2015

Variety	Average kg / tree		Agroforestry 85 trees/ha t/ha		100% apples t/ha	
	2014	2015	2014	2015	2014	2015
Pinova	2.71	3.35	0.23	0.28	2.30	2.85
Fiesta	3.12	1.60	0.27	0.14	2.65	1.36
Red Devil	2.85	4.35	0.24	0.37	2.42	3.70
Limelight	2.99	5.43	0.25	0.46	2.54	4.62
Red Windsor	1.44	4.63	0.12	0.39	1.22	3.94
Rajka	7.00	7.67	0.60	0.65	5.95	6.52
Falstaff	0.55	3.91	0.05	0.33	0.47	3.32
H Russett	2.25	7.25	0.19	0.62	1.91	6.16
Saturn	0.29	4.86	0.02	0.41	0.25	4.13
Bramley	0.41	4.36	0.03	0.37	0.35	3.71
Adams Pearmain	6.90	9.48	0.59	0.81	5.87	8.06
Ashmeads Kernel	1.72	4.60	0.15	0.39	1.46	3.91
Chivers Delight	1.79	17.86	0.15	1.52	1.52	15.18

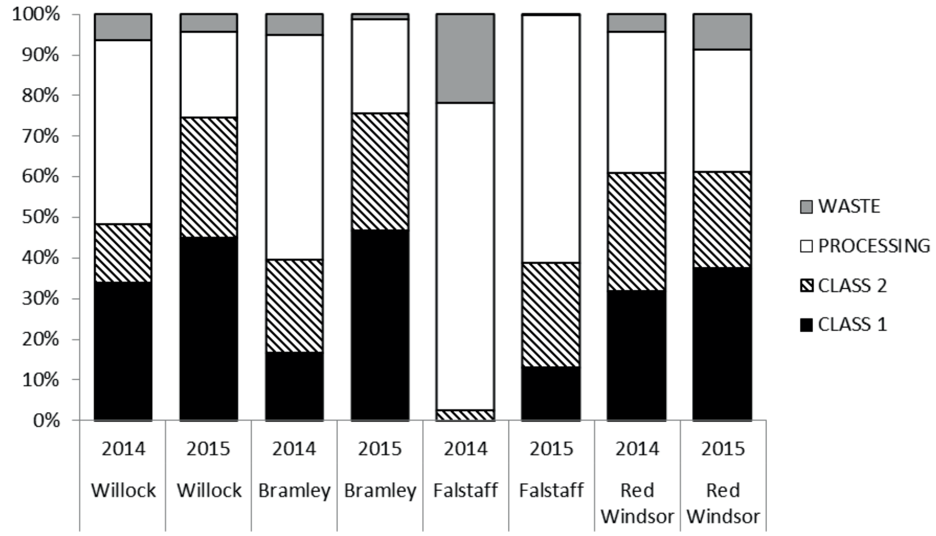


Figure 4. Percentage of each class in pre-harvested fruits 2014 and 2015

Pests and diseases

Case Study 1: Neither the agroforestry apple trees nor orchard trees are sprayed for scab, and there were high levels of scab in both systems in 2012 (Figure 5). However, scab levels of both small and large fruits were over twice as high in the orchard compared with the agroforestry site and analyses showed a statistically significant difference (small fruits $t = 4.25$, $p < 0.01$; large fruits $t = 3.44$, $p < 0.05$), but there were no significant differences between scab levels in the harvested agroforestry and orchard apples (Table 2). There was a higher incidence of insect damage to small developing fruits by sawflies ($t = -3.29$, $P < 0.05$, Figure 6a) and to large fruits by codling moths ($t = 3.94$, $P < 0.03$) in the agroforestry system compared with the orchard (Figure 6b, Table 2). At harvest, capsid damage was significantly higher in the agroforestry apples ($t = -4.57$, $P < 0.01$; Figure 6c). In 2013 scab levels of both small, large and harvested fruits were several times higher in the orchard compared with the agroforestry site (Figure 5) although due to wide variation within sites, there was only a significant difference between sites in the small fruits ($t = 3.11$, $P < 0.05$; Table 2). In the small fruit, statistically significant differences were found only for occurrences of open flesh (likely caused by birds, $t = -4.37$, $P < 0.05$; Figure 6d). In the large fruit, there were significantly higher levels of aphid damage ($t = -3.17$, $P = 0.05$) and moth damage ($t = -2.66$, $P < 0.05$) in the agroforestry, and significantly higher levels of codling moth damage in the orchard ($t = 8.69$, $P < 0.01$, Figure 6e). There were no significant differences found in the harvested fruit (Figure 6f).

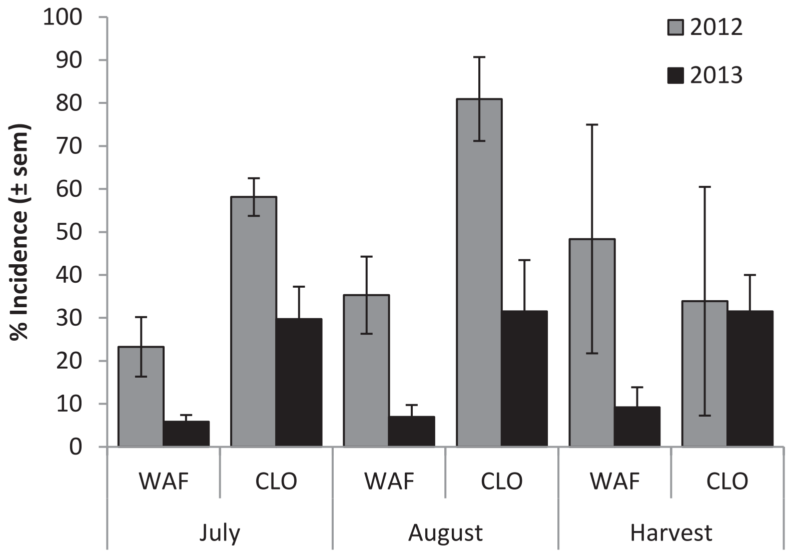


Figure 5. Mean scab incidence per plot in the agroforestry (WAF) and orchard (CLO) in 2012 and 2013

Table 2. P-values of t-tests comparing diseases and pests in the agroforestry and orchard plots

	Small fruit		Large fruit		Harvested fruit	
	2012	2013	2012	2013	2012	2013
Scab	**	*	*	NS	NS	NS
Sawfly damage	*	NS	NS	NS	NS	NS
Capsid damage	NS	NS	NS	NS	**	NS
Codling damage	NS	NS	*	**	NS	NS
Aphid damage	NS	NS	NS	*	NS	NS
Moth damage		NS		*		
Open flesh	NS	*	NS	NS	NS	
Brown Rot			NS	NS	NS	NS

* P ≤ 0.05; ** P < 0.01; *** P < 0.001, NS = not significant, Blank = no incidences recorded

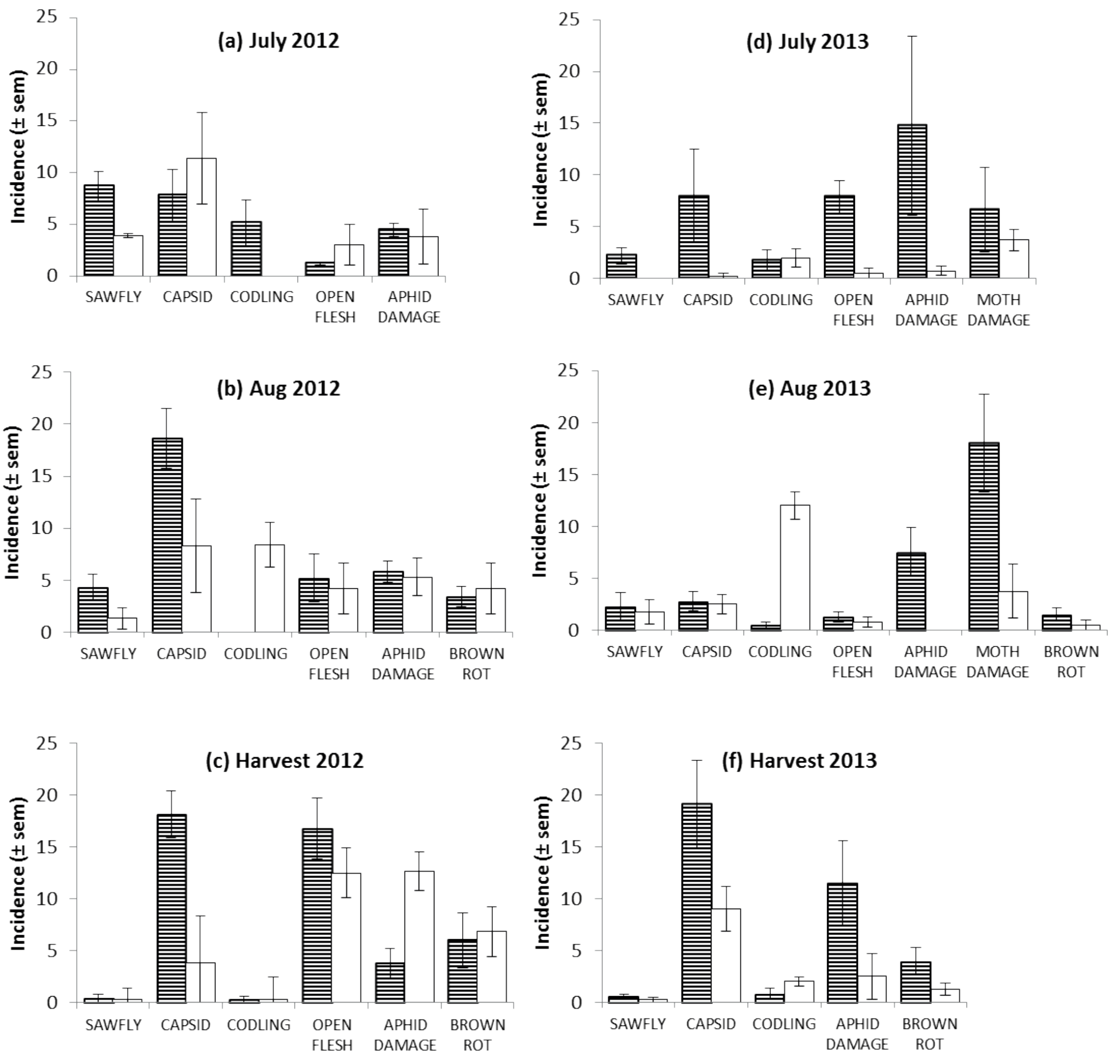
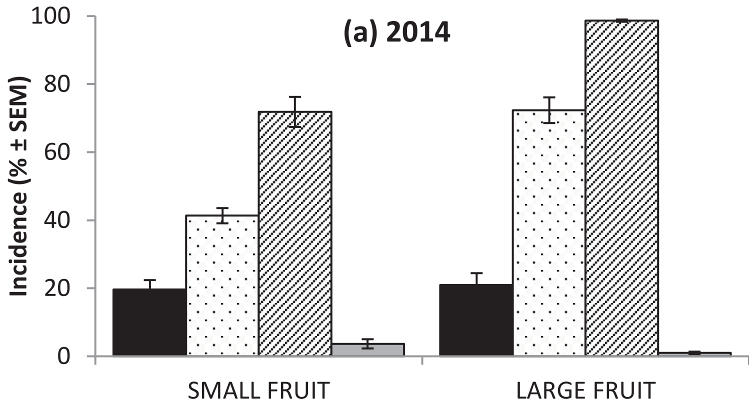


Figure 6a-f. Pest and disease damage to fruit in the agroforestry (striped bars) and orchard (white bars) in 2012 and 2013

Case Study 2: In 2014, there were high levels of scab in the Bramley and Falstaff varieties in the agroforestry, despite Falstaff being a moderately resistant variety (Table 3, Figure 7a). The Red Windsor apples maintained their resistance to scab. Levels of scab in the orchard were just under 20%. Analysis of variance identified a highly significant difference between all samples in both the small fruit ($F = 93.54$, $P < 0.001$) and large fruit ($F = 279.9$, $P < 0.001$). Scab levels were overall lower in 2015, although analyses found a significant difference in both the small fruit ($F = 50.93$, $P < 0.001$) and large fruit ($F = 193.7$, $P < 0.001$); this difference was due to much higher levels recorded in the Falstaff plots (Figure 7b).



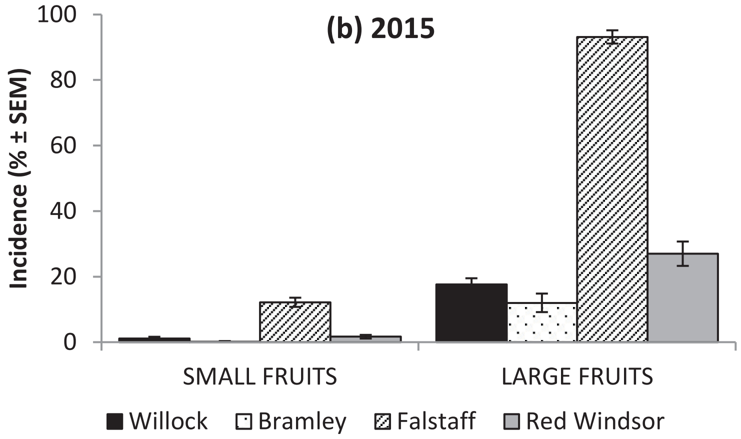


Figure 7. Mean scab incidence per plot at Whitehall Farm and Willock Farm orchard in July and September 2014 (7a) and 2015 (7b)

Table 3. P-values of ANOVAs comparing diseases and pests in the agroforestry and orchard plots in 2014 and 2015

	Small Fruit (July)		Large Fruit (Sept)	
	2014	2015	2014	2015
Scab	***	***	***	***
Sawfly damage	*	***	NS	NS
Capsid damage	***	***	***	NS
Codling damage	***		***	NS
Open flesh	NS	*	***	***
Aphid damage	NS	**	*	*
Brown Rot	NS		***	***
Moth damage	***	NS	***	***
Earwig damage				***

* P≤0.05; ** P<0.01; *** P<0.001, NS = not significant, Blank = no incidences recorded

A range of secondary pests and diseases were recorded in the agroforestry and orchard systems in 2014 and 2015 (Figure 8, Table 3). In 2014, moth damage was common in the Bramley and Falstaff apples, as were open flesh wounds caused by insects and/or birds, while

Red Windsor suffered high levels of capsid damage (Figure 8a and b). In 2015, sawfly damage was the main problem in the developing fruits, despite the removal of infected fruit in the agroforestry systems in June 2015, with highest levels in the Willock and Falstaff small apples ($F = 39.71$, $P < 0.001$, Figure 8c). In the large fruit, Bramley apples suffered from higher levels of moth damage ($F = 25.59$, $P < 0.001$) and earwig damage ($F = 79.99$, $P < 0.001$, Figure 8d).

Impact on management activities

(i) Motives for establishing silvoarable agroforestry

The most commonly held objective was economic diversification. Perceived benefits of diversification included enhanced biodiversity, reduced economic risk and resilience to climate change. The second most common objective was improved biodiversity, with interviewees citing habitat creation and improved pest-predator balances as a desired consequence. Individually held motives for implementing silvoarable agroforestry varied with farm location and business type and included soil protection and extended cropping season. Three out of the four case study systems were thought to have been successful in meeting the main objectives behind their implementation, with the fourth case study being too recently established to draw conclusions.

(ii) Observed benefits and challenges in regards to the main management activities of both arable and apple production

One of the main benefits of agroforestry identified by farmers was the provision of shelter for arable crops and vegetables, and reducing soil erosion. A second important benefit highlighted by farmers was for biodiversity, with reported increases in small mammals, farmland birds and increased habitat for beneficial insects. One farmer reported reductions in pests and disease within their system. Weed management was identified as one of the main management impacts associated with silvoarable systems. There was a general consensus that effective management of the understory is required to ensure tree rows do not become a reservoir for arable weeds. A number of trade-offs were identified with regards to pests. Although one farmer reported increased biodiversity they also recognised that not all increases had been positive, highlighting an increase in deer presence. Similarly, another farmer reported that although the trees provided shelter for early vegetables, they also provided cover for rabbits and had observed increased rabbit damage as a consequence. Apple storage also presented a challenge to three out of the four farmers due to product perishability and limited on-farm storage facilities. Being predominantly arable farmers, most had little experience of managing trees before establishing their agroforestry system and so a lack of knowledge in terms of both technical design and operation of silvoarable systems was a major challenge during system establishment.

(iii) Future adoption of silvoarable agroforestry within the UK

With regards to adoption, all farmers stressed the importance of knowledge transfer between farmers already managing silvoarable systems and those interested in implementing them. Farmer-led adoption was evident with two of the case study systems having been inspired by an earlier adopter. A lack of supporting subsidies and conversion grants within the UK for agroforestry was recognised by all of the farmers as a major barrier to system adoption. Farm tenancy was raised by three of the farmers as an issue for agroforestry adoption due to the long lifespan of trees in comparison to tenancy agreements.

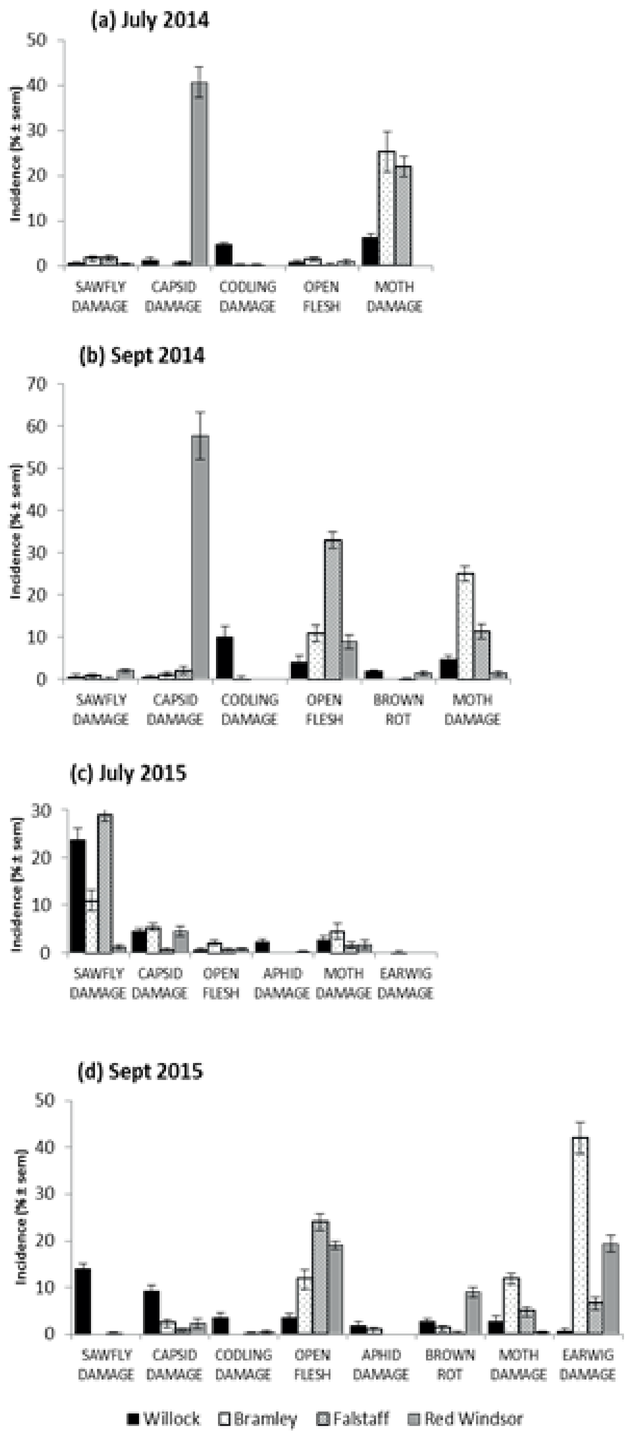


Figure 8a-d. Pest and disease damage to fruit in the agroforestry and orchard plots in 2014 and 2015.

Discussion

Yields at Wakelyns in 2012 and 2013 were comparable with standard figures when scaled up from 2.5% land area under apple production to 100% apples and, even at just 2.5% cover, appeared to out-perform the organic orchard used for comparison. With so few apple trees this would probably not be acceptable for large scale apple producers who rely on economies of scale. However, this approach could work well in a diverse, potentially small-scale system such as a market garden, where apples could contribute to direct marketing channels such as vegetable box schemes or farm shops. Having such a wide range of varieties within the system means that harvesting would occur over a longer period. This requires careful planning and may be a challenge for selling to wholesalers if only small amounts are ready at any one time. New approaches to marketing could address this problem, for example, creating mixed bags of varieties, categorising by taste, e.g. ‘sweet’ apple bag, or ‘sharp’ apple bag; or by making more of a feature of the varieties if going into vegetable box schemes e.g. ‘apple of the week’.

In the more commercial system at Whitehall Farm, tree rows account for 10% land area with 85 trees/ha; scaling up to 100% apples, yields compared well with standard yields. Considering that the apple trees at Whitehall were planted only in 2009 and so the system is still establishing and developing, the apple yields look promising, with some varieties performing much better than others.

Neither case study systems spray to control for scab or other diseases or pests, and scab was detected in both systems during the years of study. At Wakelyns, scab levels were several times lower than in the nearby organic orchard in both 2012 and 2013. Although no firm general conclusion can be drawn from this case study, it appears as if there may be indications of a potential positive impact on reducing scab levels within the agroforestry. This could be due to the very low densities and high diversity of apple tree varieties. Also, that while some varieties may fail to set fruit or have high levels of scab, the high diversity of apple varieties within the agroforestry means that other varieties will compensate and so buffer against extreme losses of yields. However, further research will be required to confirm this theory.

Scab was recorded in the apples at Whitehall Farm at quite high levels, particularly in 2014, and in one variety (Falstaff) in 2015, although the resistant variety Red Windsor maintained its resistance. However, the apple varieties studied seemed to perform poorly, while other varieties in the system yielded well and had fewer pests and diseases; this demonstrates the value of planting a wide range of varieties. The varieties were planted in blocks, which is likely to have facilitated the spread of pests and diseases, despite the crop alleys in between tree rows. It may therefore be better to mix varieties within the rows and fields, although this then becomes a challenge to manage and harvest efficiently.

In both case study systems, the impacts of secondary pests and diseases varied between the agroforestry systems and the orchards, This supports previous research on agroforestry systems that while some pests are reduced in agroforestry systems, other pest groups may be observed in higher numbers, and shifts in relative importance of pest groups may present novel management problems and influence crop choice (Griffiths et al., 1998).

This study provided useful insight into the potential benefits and management challenges associated with novel silvoarable apple systems. Although farmers reported a number of management issues and unforeseen challenges in the design, establishment and on-going operation of their systems, they also spoke of substantial benefits in terms of product diversification, increased biodiversity, reduced soil erosion and the provision of shelter, with most believing that their systems had been successful in meeting their objectives, suggesting such benefits may well outweigh any management inconveniences. Nevertheless, a number of approaches to mitigating the management impacts of integrating apple and cereal production were identified. These included appropriate system design, de-synchronization of management activities, effective management of tree-crop competition and weeds, and the ability of farmers and contractors to adapt management practices.

Evidence of farmer-led adoption suggests farmers perceive silvoarable apple systems to be viable, implying scope for wider uptake within England. However the interviews also identified a number of substantial knowledge gaps. This calls for not only further documentation of existing systems but further trials on their establishment, operation and commercial performance. As recognised by all five of the farmers interviewed, in addition to continued research, favourable policy changes and conversion grants will be required for wider adoption of agroforestry-based apple production within the UK.

Potential synergies and tensions

Combining apple production with arable production aims to maximise synergies between the different components while minimising negative interactions. Potential synergies within the two case-study systems, including those identified by the farmers, include increased biodiversity resulting in increases in natural enemies; high diversity of apple varieties reducing diseases and spreading risk from crop failure; and shelter from trees reducing wind impacts on arable and vegetable crops. However, trade-offs were also identified. For example, encouraging apple pollinators in an arable system using floral mixtures as at Whitehall Farm may also lead to increases in certain pests e.g. capsids. And while there may be benefits of increasing varietal diversity, reducing tree densities and encouraging mixed plantings of varieties in terms of reducing the spread of disease, this would have implications for efficient harvesting, management and marketing.

Conclusion

The two case study systems provided contrasting approaches to agroforestry-based apple production in terms of scale and design. The low density, high diversity approach at Wakelyns Agroforestry seemed to have benefits in terms of reducing disease levels, and could work well in a diverse, potentially small-scale system such as a market garden, where apples could contribute to direct marketing channels such as vegetable box schemes or farm shops. The commercial silvoarable system at Whitehall Farm showed that an agroforestry approach *per se* is not successful at reducing scab levels. However, if combined with careful selection of resistant varieties and, if possible, mixed planting of varieties, the other benefits that agroforestry brings, particularly to arable systems, may make this approach attractive to arable farmers looking to diversify their enterprises or protect their farms against environmental problems.

Acknowledgements

With great thanks to Professor Martin and Anne Wolfe, Wakelyns Agroforestry, and Stephen and Lynn Briggs, Whitehall Farm, for their enthusiasm, support and cooperation in this research. Thanks also to Mr Jim Cooper for access to his organic orchard and his help with harvesting and assessments. We are grateful to the farmers who participated in the interviews and value their input. This research was carried out within the CO-FREE project (grant agreement number 289497; duration 54 months) which is funded by the European Commission in FP7. This project is coordinated by Dr Annegret Schmitt with the support of Dr Sara Mazzotta (Julius Kühn Institute), and deputy coordinator Dr Lucius Tamm (FiBL).

References

Carisse, O., & Dewdney, M. (2002). A review of non-fungicidal approaches for the control of apple scab. Phytoprotection 83: 1-29.

Griffiths, J., Phillips, D.S., Compton, S.G., Wright, C., Incoll, L.D. (1998). Responses of slug numbers and slug damage to crops in a silvoarable agroforestry landscape. Journal of Applied Ecology 35: 252-260.

Hennink, M., Hutter, I., & Bailey, A. (2010). Qualitative Research Methods. London: SAGE Publications Ltd.

Lampkin, N., Measures, M., & Padel, S. (Eds) (2014). 2014 Organic Farm Management Handbook. University of Wales.

Pretty, J.N., Guijt, I., Thomson, J., & Scoones, I. (1995). A Trainer's Guide for Participatory Learning and Action. IIED.

Provalis Research (2015). www.provalisresearch.com/products/qualitative-data-analysis-software/.

R Development Core Team (2009). R: A language and environment for statistical computing. In: R Foundation for Statistical Computing.

Schroth, G., Balle, P., & Peltier, R. (1995). Alley cropping groundnut with *Gliricidia sepium* in Cote d'Ivoire: effects on yields, microclimate and crop diseases. Agroforestry Systems 29: 147-163.

Schroth, G., Krauss, U., Gasparotto, L., & Duarte, J.A. (2000). Pests and diseases in agroforestry systems of the humid tropics. Agroforestry Systems 50: 199-241.

Managing traditional hedges for biofuel

Westaway, S.[1], Chambers, M. [1], Crossland, M. [1], Wolton, R.[2] and Smith, J. [1]

[1] *The Organic Research Centre, Hamstead Marshall, UK*

[2] *Locks Park Farm, Okehampton, Devon, UK*

Abstract: With around 700,000 km, hedges are the most widespread semi-natural habitat in lowland Britain. As well as being an important landscape feature in their own right, hedges fulfil many functions and are increasingly recognised for their importance in regulating environmental processes. However, the 2007 Countryside Survey found that just 68% of Britain's hedges are managed. Recent research has sought to address this by investigating the economic potential of using biomass from hedgerow management for local energy or heat production. This work has brought farm hedges back into focus and sought to answer questions about whether biomass can be sustainably and economically harvested from hedgerows, and as such, whether hedges can be a viable source of woodfuel? Here we outline the results of trials carried out in southern England to assess the efficiency, cost and viability of coppicing hedges as a local and sustainable source of woodfuel. Machinery and methods were tested at different scales and the impacts on the local environment assessed. Building on work in south west England and northern France the trials demonstrated that hedges can be managed effectively and economically to produce woodfuel of reasonable quality which meets industry standards. However, the introduction of coppice management of hedges for woodfuel is likely to have both positive and negative impacts on the wildlife of individual hedges and on biodiversity at a landscape scale. To address this, alongside the trials a protocol was developed to assess the likely impacts on biodiversity of managing hedgerows for woodfuel. The biodiversity protocol enables landowners to carry out an assessment of their resource prior to carrying out any management, it identifies hedges suitable for harvesting woodfuel and those of potentially high biodiversity value as well as those in need of improvement, and offers general management recommendations based on different indicators.

Keywords: Hedges, woodfuel, biodiversity

Introduction

With around 700,000 km, hedges are the most widespread semi-natural habitat in lowland Britain (Carey et al., 2008). As well as being a characteristic feature of the British countryside, hedges fulfil many functions, ecological and social, and are increasingly recognised for their importance in regulating environmental processes (Wolton et al., 2014). The abundance of hedgerows in landscapes otherwise dominated by agriculture makes them a vital resource for biodiversity (Baudry et al., 2000). Biodiversity in British hedgerows has been well studied and hedgerows have been found to offer multiple micro-habitats, food sources and ecological corridors for a diverse range of flora and fauna (Baudry et al., 2000; Vickery et al., 2009). However, despite the multifunctional nature of hedges and their importance in the provision of ecosystem services, the 2007 Countryside Survey found that just 68% of Britain's hedges are actively managed, with only 40% classed as being in good condition (Carey et al., 2008). The main threat to hedges and the services that they provide are changes in management practices related to agricultural intensification and a reduction in the perceived value of hedges to farmers (Oreszczyn & Lane, 1999). Of those hedges that are still actively managed the majority are repeatedly flailed at the same height, eventually creating gaps and leading to a decline in hedge condition, whilst those left unmanaged will ultimately develop into lines of trees. The results of both over and under management are detrimental to the structural integrity of the hedgerow (Garbutt & Sparks, 2002) and hence the quality of this important biodiversity resource. To maintain them into the future this imbalance in management needs to be addressed. Hedges need periodic rejuvenation actions, either by coppicing or hedge laying; however these management options are costly, time consuming and often missing.

Recent research (Chambers et al., 2015; Wolton, 2012) has sought to address this lack of appropriate management by investigating the economic potential of using biomass from hedgerow management activities for local energy or heat production. Coppicing or hedge-laying are both rejuvenation methods that can produce woodfuel as a by-product, either directly as logs or chipped for use in biomass boilers. Therefore management for woodfuel could provide an opportunity to rejuvenate old hedges, restoring not only their economic role but their value to the wider landscape. In some areas of northern France, hedgerows are coppiced and still provide an important fuel source, producing 4.4 million cubic metres of fuel per year and accounting for 11% of the total firewood used by households in 1997 (Lotfi, 2010). Recent trials in south west England investigated the relative costs and biomass production of hedge laying and coppicing, both carried out manually using a chainsaw. These trials showed that laying can retain up to 70% of material in the hedge and takes a lot longer (Wolton, 2012). Lessons from the continent combined with the work in south west England indicate that coppicing and chipping all the cut material is the most economic management method for woodfuel production (Wolton, 2012). However, hedge laying can also produce reasonable quantities of usable fuel wood and is the traditional UK management practice for producing a stock-proof field boundary. Given their significance in supporting biodiversity, if hedgerow coppicing is to be promoted as a management method for the provision of woodfuel, any potential impacts on biodiversity both within the hedgerow network and the landscape need to be assessed. In areas with specific landscape and biodiversity priorities hedge laying may be the most appropriate rejuvenation technique, especially where it is important that landscape connectivity is maintained.

Despite increasing interest in managing hedges for woodfuel and the potential benefits, there is limited data and knowledge regarding the productivity, logistics and potential impacts of such systems. Here we outline the results of trials carried out by the Organic Research Centre (ORC) at two sites in southern England (Chambers et al., 2015) as part of the European project Towards Eco-Energetic Communities (TWECOM; www.twecom.eu). The trials assessed the feasibility of mechanising the process of coppicing hedges and processing the resultant material as a local and sustainable source of woodfuel.

Methods

The trials were carried out during winter 2014/15 at two sites: Elm Farm, Newbury, West Berkshire (51.23°N; 1.24°W) and Wakelyns Agroforestry, near Diss, Suffolk (52.36°N 1.36°E). Three different hedges were used, representing a range of physical characters but all at a suitable stage for coppice management. In addition, in winter 2013, three small plot trials were established at Elm Farm (Table 1).

Table 1. The trial hedges at Elm Farm and Wakelyns Agroforestry

Site	ID	Length of coppiced section	Hedge description	Approximate hedge dimensions
Wakelyns Agroforestry	Hedge 1	100 m	Mixed species, small field maple trees, hawthorn and some blackthorn, dogwood. Left to grow for c.20 years	7.5 m high, 3.5 m wide
	Hedge 2	20 m	Predominately hazel coppice with several small multi-stemmed field maple trees. Last coppiced c.15 years ago.	4 m high, 2 m wide
Elm Farm	Hedge 3	170 m	Predominantly mature hazel coppice plus substantial blackthorn outgrowth. Last coppiced c.28 years ago.	6 m high, 3-5 m wide
	Blackthorn small plot	15 m	Predominantly very overgrown blackthorn, internal ditch. Blackthorn stems c.40 years old.	5.5 m high, 4 m wide
	Hawthorn small plot	15 m	Predominantly mature hawthorn with some willow on one bank, internal ditch. Hawthorn stems c.40 years old	5 m high, 4 m wide
	Hazel small plot	15 m	Predominantly mature hazel coppice, deep internal ditch. Last coppiced c.15 years ago.	6.5 m high, 6 m wide

Machinery and methods were selected to represent a range of machinery sizes, cutting mechanisms, cost and availability. Machinery was classified as small-, medium- and large-scale, and one machine of each scale was trialled at each site. The large-scale harvesting machinery trialled were hydraulic shears and a felling grapple with integral chainsaw; medium-scale were assisted fell (manual fell using a chainsaw and excavator) and tractor-mounted circular saw; and small-scale was manual felling at both sites. Two sizes of chippers were also trialled: a large drum chipper and a small disc chipper. All machinery was operated by experienced contractors.

The trials assessed: the costs associated with each machinery option and the time taken to coppice or chip a pre-determined length of hedge; the biomass productivity of each hedge; and the chip quality in terms of moisture and ash content, calorific value and particle size distribution (ÖNORM and BS EN standards). At Elm Farm, coppice regrowth and stool survival was also monitored for Hedge 3 during the summer following coppicing and again at the end of the growing season to ascertain the impact of different cutting methods on stool health and regrowth. Monitoring plots of 15 m length were measured out in each of the five hedgerow coppicing trial sections: hydraulic tree shears (left as cut); hydraulic shears (with short chainsaw finish); hydraulic tree shears (with long chainsaw finish); assisted fell; and manual fell. Both the number of shoots and the height of the five tallest stems were recorded for each stool within these 15 m plots.

Small plot trials

The aim of the small plot trials, which were carried out prior to the machinery trials, was to refine non-destructive methods to assess the volume of biomass in a hedgerow; to quantify coppice re-growth and survival rates between different hedgerow species; and to assess the impact of coppicing on biodiversity, microclimate and soil carbon dynamics. Paired 15 m cut and uncut plots were established in three different hedgerow types: blackthorn, hawthorn and hazel dominated (Table 1). Coppicing was carried out in winter 2013 by hand and all material was chipped, bagged and weighed. Regular regrowth measurements were carried out on the cut stools.

Results

Harvesting and chipping costs

Both harvesting and chipping costs per metre were calculated by dividing the day hire cost including haulage by the length of hedge each machine can harvest or chip in one day, to give the maximum efficiency of each option. The harvesting and chipping cost and time taken per metre varies depending on hedge type and length coppiced, and variability within methods was seen depending on the hedge (Table 2). For example, manual fell was generally the most time consuming method but the time taken to coppice 1 m of hedge varied between 10.8 and 12.8 minutes depending on the hedge. Assisted fell was found to have the lowest harvest cost per

Table 2. The harvesting and chipping cost and time taken per metre for each machinery option at Elm Farm and Wakelyns Agroforestry

Machinery option	Hedge/ location	Cost per metre of hedge	Minutes per metre of hedge
10” Dymax tree shears	Hedge 3	£6.78 £8.06[a]	2.78 3.30[a]
Gierkink felling grapple	Hedge 1	£6.28	2.64
Tractor mounted circular saw	Hedge 1 Hedge 2	£7.46 £4.00	5.40 2.90
Assisted fell (chainsaw and excavator with land rake)	Hedge 21	£2.26	1.58
Manual fell (2 person team with chainsaw)	Hedge 21 Hedge 1	£6.85 £8.24	12.85 10.81
Heizohack fuel grade chipper	Elm Farm	£3.21	1.48
Jenz drum chipper	WAF	£2.44	1.63
6” Timberwolf chipper	Elm Farm	£5.01	5.01

[a]*: with chainsaw finish*

metre (£2.26) and was also one of the least costly options. Haulage increased the cost of the large-scale machinery options. On average it was found to be cheaper and quicker to use large scale chippers; of the chipping options trialled the Jenz drum chipper had the lowest processing cost per metre (£2.44), followed by the Heizohack drum chipper (£3.21) and the Timberwolf disc chipper had the highest processing cost (£5.01), however these figures are dependent on the amount of material to be processed.

The energy cost of hedgerow woodchip ranged from 1.6 to 3.5 pence per kWh depending on machinery options and hedge type. This compares relatively favourably with the cost of commercially produced woodchip from forestry roundwood which retailed at 3.43 pence per kWh in 2015 (Forest Fuels, 2015).

Biomass

Biomass data was collected from six different hedges, the three machinery trial hedges and three small plot trials at Elm Farm. Average biomass production per metre hedge, at 30% moisture content, was 82 kg, or 8.2 tonnes per 100 m. Production ranged from 4 to 13 tonnes per 100 m depending on hedge species, structure and age, with the blackthorn small plot showing the highest biomass production (Figure 1).

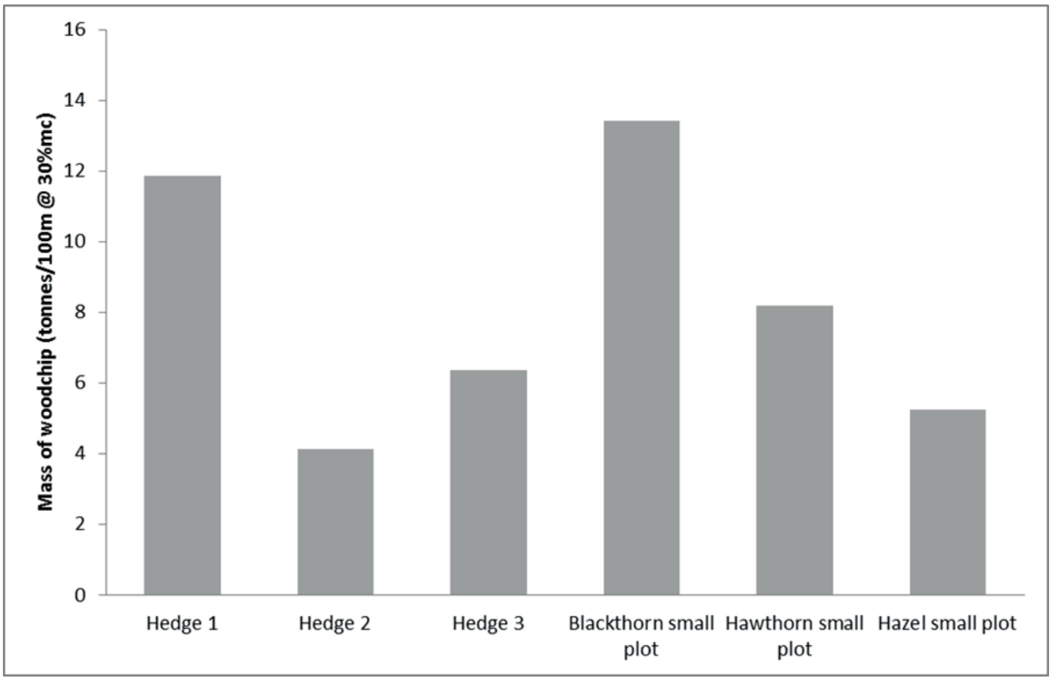


Figure 1. Mass of woodchip produced by each of the different hedges (tonnes per 100 m at 30% moisture content)

Chip quality

It was expected that the large drum chippers with integral screens would produce higher quality woodchip than the smaller disc chipper. However, when tested there was no difference in chip quality between the different chippers. The woodchip quality analysis found that all the hedgerow samples passed the BS EN standards and ÖNORM G30 standards for particle size distribution, indicating that a suitably high proportion of the hedgerow woodchip was greater than 30 mm in diameter, and therefore saleable on the open woodchip market. They did however all fail the ÖNORM G50 standards; this was due to the generally smaller diameters found in hedgerow material. There was very little variation in calorific value between the three different hedges sampled. However the drying method appeared to affect both the ash content and the moisture content of the woodchip. The ash content of hedge material that had been left to air-dry in the field for three months ranged from 2.06% to 2.93% and the average moisture content was 24%. However where the material was chipped green the ash content was significantly higher at 3.58% and the moisture content after three months was 31%.

Regrowth

Two of the three sections cut with the hydraulic tree shears were finished with a chainsaw (long and short finishes) to tidy them up and remove the split stems produced by the shears. In Hedge 3 an average of 1.1 m regrowth from hazel coppice stools was seen after seven months, increasing to1.5 m by the end of the first growing season, re-establishing a green roadside and landscape feature, and habitat continuity and wildlife corridor. No significant difference in regrowth was seen between the different cutting methods (Figure 2). The plots coppiced using the assisted fell and tree shears (both long and short chainsaw finishes) had the highest average number of shoots per stool, at 89.9 and 85.9 respectively, followed by manual fell with 77.4 and then the tree shears (left as cut) which only had 60.5 shoots per stool on average. This variation between plots may be due to variation in growing conditions and stool sizes along the hedge or the health of the stools before coppicing.

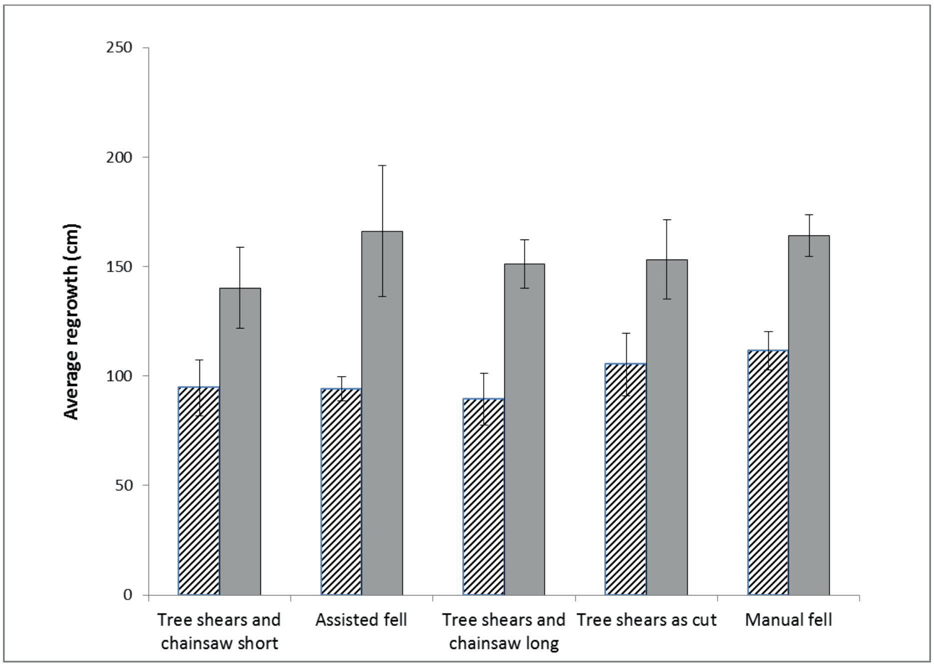


Figure 2. Average regrowth (± SE) of different treatments in Hedge 3 plots: diagonal shading measured in June 2015; solid shading in November at the end of the growing season

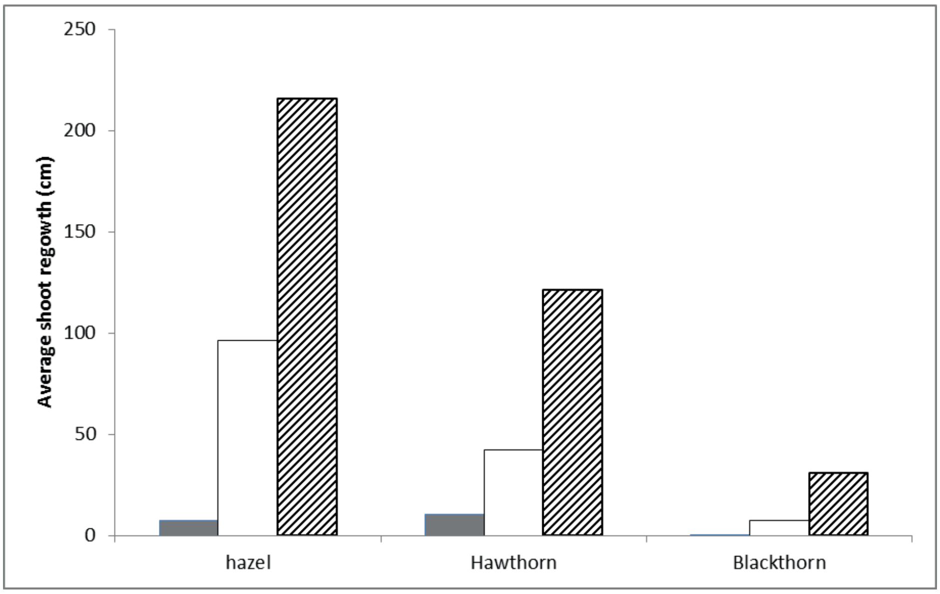


Figure 3. Average shoot regrowth in cm of small single species plots at Elm Farm: solid shading was measured in May 2014; unshaded bars were measured in July 2014; diagonal shading measured in July 2015

Regrowth in the small plot trials showed large differences in average regrowth between different hedge species (Figure 3). Blackthorn stools were very slow to regrow, many cut stems did not show any regrowth at all, and much of the regrowth that was recorded was from underground suckers. By contrast the regrowth in the hazel plots was strong, with an average of 1.21 m by July 2015; the hawthorn stools also showed strong regrowth.

Biodiversity impacts

Change in management adopted on any scale has potential impacts and the introduction of coppice management to hedges for woodfuel is likely to have both positive and negative impacts on the wildlife of individual hedges and on biodiversity at a landscape scale. Potential impacts include an alteration of the hedge microclimate, changes in hedge structure, plant species composition, and landscape connectivity. It is expected that the introduction of coppice management cycles will tend to make hedgerow systems more dynamic, increasing the habitat heterogeneity within a landscape. With different species and communities associated with different ages of regrowth, this may lead to an increase in overall biodiversity at a farm or landscape scale. However there are also likely to be some trade-offs, for example, reduced connectivity between patches of semi-natural habitat for species that use the hedgerows as corridors, such as dormice (*Muscardinus avellanarius*) which have been found to be gap adverse (Bright, 1998) and may be adversely affected by coppicing.

To address this alongside the practical trials, a biodiversity protocol was developed by ORC (Crossland et al., 2015) to assess the likely impacts on biodiversity of managing hedgerows for woodfuel. This protocol provides a simple methodology to enable landowners to assess the biodiversity status of a hedge network prior to changes in management. It gives baseline data for comparison whilst also identifying hedges that are home to key species with specific management requirements. The protocol is based on a set of indicators selected to provide quantitative links between, for example, habitat quality or structural diversity and biodiversity (Dauber et al., 2003). In order to make the results widely relevant, the methodologies developed to measure each indicator were based on existing surveys such as the DEFRA hedge survey (DEFRA, 2007) and the British Trust for Ornithology's breeding bird survey. The main indicators included in the protocol are: hedge connectivity, hedge network density, the density of hedgerow trees, hedge structural diversity, the percentage of hedges in favourable condition, and the percentage of hedges providing a good food resource. After carrying out the survey these indicators are scored and the results represented visually using a radar diagram (Figure 4). This gives an overall picture of the biodiversity value of a hedge network and the relative value of individual hedges within the network. Using data collected in the survey the protocol also identifies hedges suitable for harvesting woodfuel as well as those in need of improvement and offers general management recommendations based on different indicators.

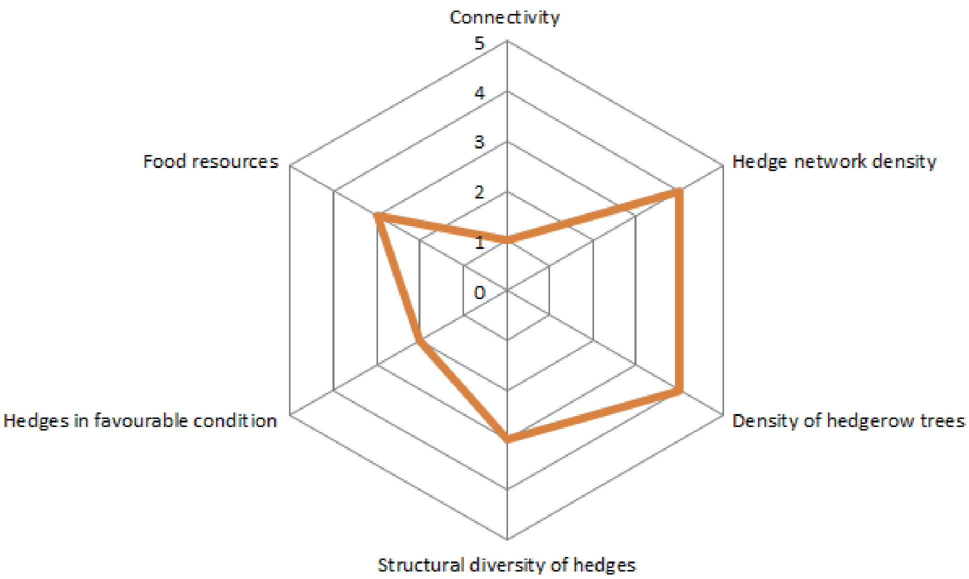


Figure 4. An example radar diagram of the biodiversity protocol hedge survey indicator results

However the protocol has not been fully tested to date and represents just one approach to quantifying hedgerow biodiversity. There are many other assessment methods and potential indicators which were not included. Through future use, the protocol could be further developed and improvements made to the indicators and how they are calculated and scored. The protocol is available online at http://tinyurl.com/TWECOM.

Conclusions

The ORC trials have demonstrated that hedges can be managed effectively and economically to produce woodfuel of reasonable quality which meets industry standards at an energy cost competitive with other fuel types. The economic case for managing hedges for woodfuel is further strengthened when additional savings in reduced costs of annual flailing are taken into account, plus the potential government support via environmental stewardship payments.

A key conclusion from the ORC trials is that each hedge is unique and has to be assessed and managed on its own merits and the most appropriate machinery or methods will depend on the hedge itself and the priorities of the landowner or farmer. In these trials the harvesting and chipping options were used on different hedge types and as such it is difficult to make direct comparisons between the machines. However some general conclusions can be drawn. Assisted fell and large chipper was the most cost-effective harvesting and processing combination of all the machinery methods trialled when at least 280 m of hedge was coppiced. Smaller sections are likely to be more suited to manual fell techniques and smaller chippers. Both the hydraulic shears and felling grapple appeared better suited to large-diameter single-stemmed material with single-blade circular-saws optimally designed for small-diameter material. The assisted-fell and manual-fell methods have the flexibility to work on most sites and hedges. As shown by the variation in maximum efficiency of the circular-saw and manual-fell options when used on different hedge types, the nature of the hedge material being coppiced can have a significant effect on the performance of harvesting options.

The biodiversity protocol provides a mechanism with which to assess a hedge network prior to management in order to identify hedges suitable for harvesting woodfuel, those with high biodiversity value, as well as those in need of improvement. These trials demonstrate that, managed correctly, the use of traditional farm boundary hedges for woodfuel can be both economically viable and beneficial, not only in terms of energy production but also by making sense environmentally, for example, in terms of improving the long-term viability of hedges, connectivity in the landscape and carbon sequestration.

The next step is to investigate how to increase the quality of the woodchip from hedgerows and the potential for other new products from the woodchip such as landscaping mulch, compost, or livestock bedding. Starting in March 2016, 'SustainFARM' is a new EU funded project which will look further into these other provisioning services as well as model the agronomic, environmental and economic performance of these and other integrated food and non-food production systems.

Acknowledgements
The TWECOM project was supported by European Regional Development funding through INTERREG IVB NWE, and funding from the Ashden Trust, the Woodland Trust, the North Wessex Downs Sustainable Development Fund and the Gerald Palmer Eling Trust.

References

Baudry, J., Bunce, R.G.H., & Burel, F. (2000). Hedgerows: an international perspective on their origin, function and management. Journal of Environmental Management 60: 7-22.

Bright, P.W. (1998). Behaviour of specialist species in habitat corridors: arboreal dormice avoid corridor gaps. Animal Behaviour 56: 1485-1490.

Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M., & Ullyett, J.M. (2008). Countryside Survey: UK Results from 2007. CEH Project Number: C03259, 105 pp.

Chambers, E.M., Crossland, E.M., Westaway, S., & Smith, J. (2015). Hedgerow harvesting machinery trials report for TWECOM. The Organic Research Centre. http://tinyurl/TWECOM

Crossland, E.M., Westaway, S., Gerrard, C., & Smith, J. (2015). Hedgerow Biodiversity Protocol 2015. User Guide. A protocol for monitoring the impacts of harvesting hedges for woodfuel. The Organic Research Centre. http://tinyurl/TWECOM

Dauber, J., Hirsch, M., Simmering, D., Waldhardt, R., Otte, A., & Wolters, V. (2003). Landscape structure as an indicator of biodiversity: matrix effects on species richness. Agriculture, Ecosystems and Environment 98: 321-329.

DEFRA (2007). Hedgerow Survey Handbook. Available from: https://www.gov.uk/government/publications/hedgerow-survey-handbook

Garbutt, R.A., & Sparks, T.H. (2002). Changes in the botanical diversity of a species rich ancient hedgerow between two surveys (1971 – 1998). Biological Conservation 106: 273-278.

Lofti, A., Javelle, A., Baudry, J., & Burel, F. (2010). Interdisciplinary analysis of hedgerow network landscapes' sustainability. Landscape Research 35:415-426.

Oreszczyn, S., & Lane, A.B. (1999). How hedgerows and field margins are perceived by different interest groups. Aspects of Applied Biology 54: 29-36.

Vickery, J.A., Feber, R.E., & Fuller, R.J. (2009). Arable field margins managed for biodiversity conservation: a review of food resource provision for farmland birds. Agriculture, Ecosystems and Environment 133: 1-13.

Wolton, R.J., Pollard, K.A., Goodwin, A., & Norton, L. (2014). Regulatory services delivered by hedges: the evidence base. Report of Defra project LM0106. 99 pp.

Wolton, R.J. (2012). The yield and cost of harvesting wood fuel from hedges in south-west England. Unpublished report to the Tamar Valley and Blackdown Hills AONBs. Locks Park Farm, Hatherleigh, Okehampton, Devon, EX20 3LZ

The value and potential of a ‘landscape-systems’ approach to agroforestry: insights from an Iberian context

Muñoz-Rojas, J., Pinto-Correia, T., Guiomar, N., Ravera, F., Surova, D., Guimarães, H., Godinho, S., Margarida Fonseca, A., Azeda, C. and Fonseca, C.

Instituto de Ciências Agrárias e Ambientais Mediterrânicas - Universidade de Évora, Portugal

Abstract: Agroforestry land uses are widely acknowledged to be complex social-ecological systems, and are strongly valued for their multi-functionality and capacity to deliver multiple ecosystem services. In the Western Iberian context, open forests dominated by various species of oaks and supporting various mixtures of agricultural, forestry and pastoral practices are clustered under the terms ‘*dehesas*’ in Spain and ‘*montados*’ in Portugal. These have recently been considered as exemplary land-use systems in which sustainability and resilience are enhanced by multiple interactions among their socio-cultural, economic and biophysical sub-systems. Regardless of the acknowledgement of the complexity that characterises dehesas and montados, to date most of the scientific approaches to study them have been disciplinary, or at times interdisciplinary, and only recently have transdisciplinary approaches been proposed. Furthermore, we consider that a number of the self-claimed transdisciplinary approaches to study montados and dehesas have been rather passive. In response to this, in the DYNAMO Research Group at the University of Évora (Portugal) we propose a (continuous) process of framing research on complex dehesa and montado systems based on what we generically term as a ‘landscape-systems’ approach. Our understanding of a ‘landscape-systems’ approach is firstly aimed at jointly embedding the multiple dimensions (biophysical, socio-economic and perceptive or cultural) and cross-scale interactions of land-use systems that emerge when they are considered as landscapes. This would permit breaking the boundaries that exist between scientific disciplines and also between such disciplines and the multiple spheres and scalar levels of land-use governance and practice. Additionally our proposal of a ‘landscape-systems’ approach is ultimately aimed at ‘supporting the implementation of an action-focused research programme for dehesas and montados’. This would be characterised by a full-life-cycle action schedule which can only be built in continuous and long-term interaction with stakeholders and other members of the wider citizenship, and where gaining mutual trust is key to success. We believe that this is an approach that could be explored in other agroforestry systems across Europe, especially those encountering barriers with translating research into practice and action.

Keywords: Agroforestry, montados, dehesas, systems science, landscape systems, action-oriented research

Introduction

Justification, objectives and structure of the study

Agroforestry land uses are widely acknowledged to be complex social-ecological systems, and are strongly valued for their multi-functionality and capacity to deliver multiple ecosystem services (Jose, 2009; Power, 2010). Actually, the potential efficiency of agroforestry in delivering multiple benefits to human well-being has been acknowledged for some time (Spurgeon, 1979). In the Western Iberian context, open forests dominated by various species of oaks and supporting various mixtures of forestry, pastoral and at times arable practices are clustered under the terms of '*dehesas*' in Spain and *'montados'* in Portugal. These are considered as exemplary land-use systems in which sustainability and resilience are enhanced by the multiple cross-scale interactions among their socio-cultural, economic and bio-physical sub-systems, with new properties emerging at different scales of outcomes and complex feedback loops between such interactions (Bugalho et al, 2011; Pinto-Correia et al., 2011; Sa-Sousa, 2014). Consequently one could argue that the principle that the 'sum is more than the parts' which forms the basis of systemic thinking is inherent to these land-use systems and related landscapes.

Regardless of the acknowledgement of the complexity that characterises montados, to date most of the scientific approaches adopted to study them have been disciplinary or at times interdisciplinary, and only recently have transdisciplinary approaches been proposed (Ferraz de Oliveira et al., 2016). Furthermore, we consider that a significant proportion of the self-claimed transdisciplinary approaches to study montados (and similarly with dehesas in the Spanish context) have been rather passive (McKee et al., 2015). In response to this, in the DYNAMO research group at the University of Évora (Portugal) we propose a (continuous) process for framing research on complex montado systems based on what we generically term as a 'landscape-systems' approach.

The objective of this paper is therefore to discuss the advantages and potentialities of such an approach to contribute to the management and planning of sustainable and resilient agroforestry systems, models and practices, exemplified in this case by the Portuguese montado.

The paper begins by introducing the main characteristics of the montado as a traditional agroforestry system that is currently endangered by socio-cultural, economic and biophysical changes. Later we describe the research rationale and approach tested, which begins by both analysing and interpreting the current social-ecological trends and challenges of any agroforestry system when it is considered from a landscape-systems perspective. The same section describes how the rationale and approach applied is necessarily underpinned by a long-term, continuous and bilateral collaboration between scientists and a wide range of stakeholders that act across multiple sectors and scales and frequently represent diverging viewpoints and perspectives. We subsequently analyse the (preliminary) results obtained in our own case study area over the course of more than a decade of research. We then further reflect on the implications of such results for refining the proposed analytical approach in order to support more sustainable and resilient landscape management, planning and protection frameworks and regimes, both within and beyond our own case study. Finally, we sum up by highlighting the main advantages and risks that are associated with the proposed approach, and the steps that are required for it to become fully applicable in a wide variety of agroforestry systems.

Montados and dehesas of south west Iberia

The montados and dehesas of south west Iberia are Mediterranean silvopastoral land-use systems dominated by holm oaks (*Quercus rotundifolia* Lam.,1785) and cork oaks (*Quercus suber* Lam., 1785) covering a wide range of tree stand densities (Pinto-Correia et al., 2011; Sa-Sousa, 2014). They are recognised for their capacity to deliver a wide number and variety of ecosystem services. In addition, and due to their intrinsic nature as multi-functional land-use systems, they are considered as a land-use type which has the potential to enhance the resilience and sustainability of rural and regional landscapes (Pinto-Correia et al., 2011).

Despite the acknowledgement that the montado provides multiple values and services and that it is an exemplar traditional silvopastoral system with a long history of resilience and sustainability (Pinto-Correia et al., 2013), and multiple economic (Fragoso et al., 2015), biophysical (Costa et al., 2009; Godinho et al., 2014; Guiomar et al., 2015) and governance attributes (Pinto-Correia et al., 2011; Pinto-Correia et al., 2013), there are challenges. Furthermore, challenges of relevance at global to national scales, such as climate change and associated human vulnerability, and the recent financial crisis (which has hit Portugal especially hard) are relevant at the scale and regional setting at which our study will be conducted.

In response to such challenges several strategic initiatives for regional development (e.g. Regional Strategy for Smart Specialisation in Alentejo of December 2014 and the Operational Programme for the Alentejo Region 2014-2020) are in place in our selected case study area. In such strategies the montado and its multiple products, values and services are considered as key assets for achieving sustainability and resilience beyond electoral cycles.

According to the 6th National Forest Inventory (ICNF, 2013), the two main dominant tree species in the Montado are holm oak (*Quercus rotundifolia* Lam., 1785) and cork oak (*Quercus suber* Lam., 1785), which jointly occupied 34% (11% and 23% respectively) of the total forested surface in mainland Portugal in 2010. A slight decline in the area occupied by holm oaks and cork oaks between 1990 and 2010 was highlighted in the same inventory. A similar decline was detected at the regional level for Alentejo (NUTS II). This is the Portuguese region with the highest number and surface area occupied by trees such as oak (ICNF, 2013).

The drivers, significance and potential consequences of the current overall decaying trend in the montado are widely covered in the scientific literature (Costa et al., 2009), and emphasise its ecological, economic and social relevance beyond the relative smoothness of the statistical data showing an overall decline that is constant over time.

Rationale and a systems approach to rural cultural landscapes

Our understanding of a 'landscape-systems' approach is one that aims to integrate the biophysical, socio-economic, perceptive and cultural dimensions with the cross-scale interactions within land-use systems that emerge when these are considered as landscapes (Pedroli & Pinto-Correia, 2006). This would permit breaking the artificial boundaries that exist between scientific disciplines and also between such disciplines and the multiple spheres and scalar levels of land-use governance, planning and management that jointly drive future trends in landscape change (Pinto-Correia & Kristensen, 2013).

In addition, our proposal of a 'landscape-systems' approach is ultimately aimed at 'going beyond public participation' and into active citizen-led decision making (Muñoz-Rojas et al., 2015) and in this way support the implementation of an action-focused research programme for agroforestry systems, including dehesas and montados. This needs to be characterised by a full-life-cycle action schedule which can only be built in continuous and long-term interaction with stakeholders and other members of the wider citizenship, and where gaining mutual trust is the main key to success.

To help operationalise our understanding of what a 'landscape-systems' approach might mean in practice we elaborated the working sequence that is shown in Figure 1. This figure encompasses the various elements (both structural or objective and perceived or subjective) of the landscape-system that need to be individually analysed and subsequently integrated in order to consider the social-ecological systemic nature that is inherent in landscapes (Matthews & Selman, 2006). Figure 1 also indicates the various spatial and temporal scales, and associated levels, that need to be considered simultaneously to design any actions concerning the landscape (Satake et al., 2008). According to Pinto-Correia and Primdahl (2012) the demand for public goods, such as biodiversity and cultural landscape values, are associated with the landscape level whereas, in contrast, landscape management is performed at the farm level. It is therefore clear to us that this analysis is to be best synthesized at or below sub-regional and municipal level and above the farming level. As is shown in Figure 1, this is a level at which data and information gathered at farm and landscape scales can then be summed up to quantify the potential contribution of the Montado to achieving National and Regional targets set either by the National Government (e.g. Decree-Law 155/2004 of the 30th June on the Protection of Holm and Cork Oaks) or Internationally (e.g. CAP policy reform 2015; Natura 2000 Network).

Furthermore, the sources of information required for analysis are equally important. Given the diversity and scope of information required to describe a system as complex as a landscape, there is a need for qualitative and quantitative, spatially explicit and statistical, socially elicited and secondary information of both a scientific and lay nature (see Figure 1). Last, it is eventually important to indicate how the collated information might ultimately inform the various landscape planning, management and protection actions within the European Landscape Convention (CE, 2000).

One key aspect that arises when initiating such an approach is the enormous complexity of the challenge from both a conceptual and an operational perspective. This is despite the multiple and valuable attempts that are gradually arising to use landscape as a valid conceptual tool to bridge the gaps between natural and social sciences (Pinto-Correia & Kristensen, 2013), as an optimal scale for bridging public planning and private management of land and land-use (Pinto-Correia et al., 2006) and as a critical asset for implementing transdisciplinarity (Mckee et al., 2015).

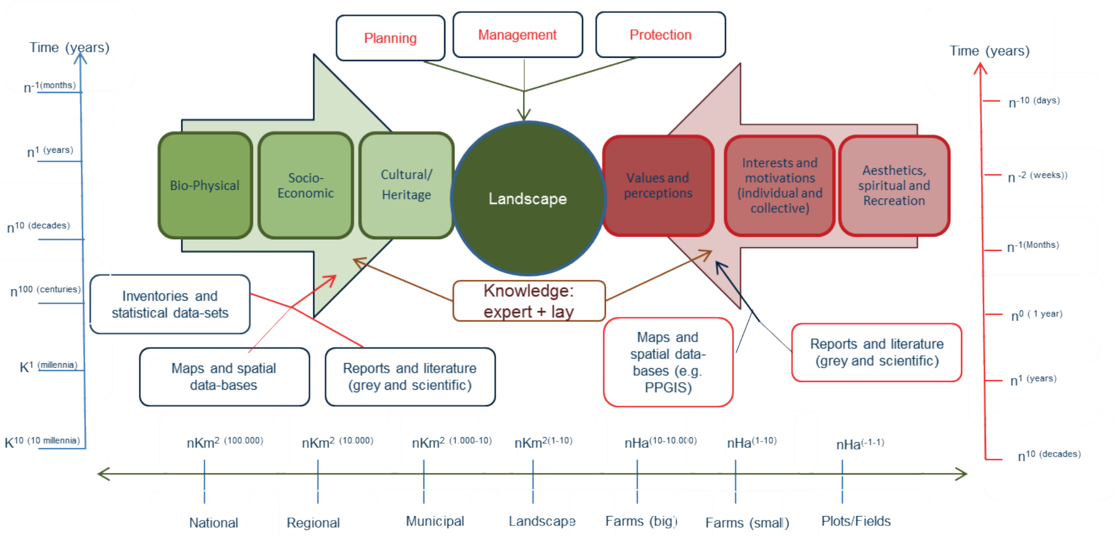


Figure 1. Elements, sources of information and scales (both in time and space) and associated levels of analysis to be considered for implementing a landscape-systems approach to study agroforestry land-use systems. Scales to be jointly considered include a temporal one of relevance for social-political processes (red vertical), a further temporal one for biophysical processes and dynamics (blue vertical) and a spatial one of relevance for both aspects (horizontal scale)

The complexity that is inherent in any landscape-based approach means that planning and managing land to achieve landscape change, sustainability, or resilience has been characterised as a 'wicked' problem, and thus partially intractable challenge (Duckett et al, 2016). The rationale and approach hereby tested is intended to contribute to addressing such wickedness, and it does so by proposing a working framework that must necessarily accomplish the following requisites: remain flexible enough to adapt to the inherent contingencies that pertain to the diverse geographical and socio-cultural contexts of potential application; incorporate as many scientific, social and professional paradigms, methods, techniques, tools, types of information and scales as potentially relevant with the ultimate goal to address landscape complexity; and engage with a wide a range of stakeholders that span beyond the traditional set of scientists, policy makers and land owners, and arrange with them the co-construction of knowledge over periods of time long enough to generate mutual trust, and favouring co-ownership of results over mere participation or collaboration.

Results and Discussion

The Montado in Central Alentejo; structure and current dynamics

Following the reasoning elaborated in earlier sections of the paper, which underpins the development of our working approach and rationale, our study takes place at sub-regional level (NUTS III), in the area of Central Alentejo (Figure 2). Regions and sub-regions represent the institutional scales at which planning and policies are best placed to link together national targets for forestry, agricultural and livestock production, rural development and nature conservation with management and decision-making practices that are realised at the plot, farming and local levels (Pinto-Correia et al., 2006; Carvalho Ribeiro et al., 2013). Furthermore, these are also the levels at which the basic guidelines and regulations for landscape planning, management and protection are actually delivered (CE, 2000).

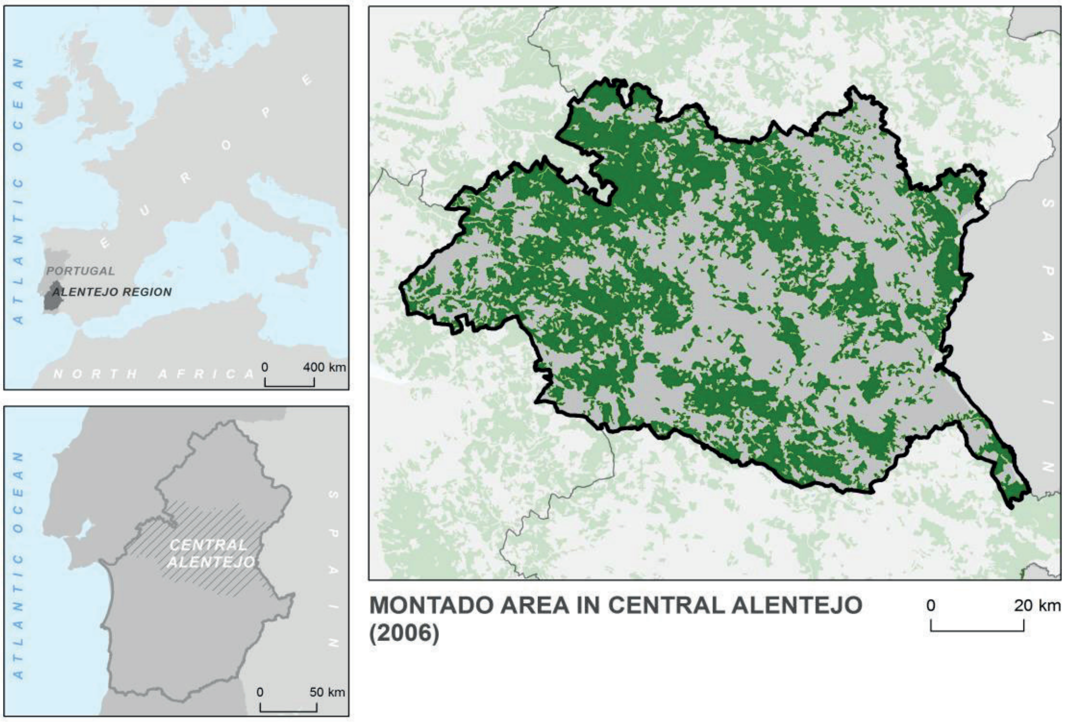


Figure 2. Location and distribution of the montado agroforestry system in the Central Alentejo region (Portugal)

In view of various technical problems encountered with the official definitions, delimitations and calculations of montados, we calculated the overall trends of change in the Montado of Central Alentejo between 1910, 1960, 1990 and 2006 using as baseline data those provided by Godinho et al. (2014). This allowed us to move beyond the consideration made both in official inventories (ICNF, 2013), scientific literature (Costa et al., 2009) and even in the relevant legislation (Decreto-lei 55/2004 de) of single tree species (holm oak and cork oak) and into considering the montado as a land-use system of a multi-functional nature (Pinto-Correia et al., 2011; Sa Sousa, 2014), characterised by a complex mosaic of spatial, ecological and landscape patterns (Pinto-Correia et al., 2011; Godinho et al., 2014). The results of this calculation for the Central Alentejo NUTS III Region are synthesized in Table 1.

According to data in Table 1, a key observation is the continuous decline after 1960 in the total surface covered by the Montado in Central Alentejo. However despite this, this land-use class still covers close to half of the region in 2000-2010. In close alignment with data for changes in holm oaks and cork oaks in the 6th National Forestry Inventory (ICNF, 2013) the decline for the Montado in Central Alentejo can be considered relatively smooth. However, by looking at other relative statistical data shown in Table 1, such as the variance and number of patches, it is clear that a trend exists towards the progressive fragmentation of the Montado. This trend may bear important consequences of ecological, territorial, socio-cultural, economic and even an aesthetic nature (Surova & Pinto-Correia, 2008; Pinto-Correia et al., 2013; Godinho et al., 2014), which can affect human well-being and that therefore demands a landscape-systems approach.

It can be argued that the progressive loss and fragmentation of the Montado may result in negative effects on the capacity of landscapes in the region to deliver multiple ecosystem public goods and services, and consequently to achieve the strategic goals for regional sustainable development set by the public authorities.

Table 1. Evolution of the main absolute and relative spatial statistical indicators of the Montado Central Alentejo (1910 to 2006) according to baseline data by Godinho et al (2016)

	1910	1960	1990	2006
Total area (km^2)	3152.95	4030.35	3544.15	3466.77
Relative area (% Central Alentejo)	43.60	55.81	49.16	47.68
Number of patches	116	208	248	306
Mean patch size (km^2)	27.18	19.38	14.29	11.33
Variance (%)	5.54	4.41	3.71	3.35
Maximum patch size (km^2)	1838.86	2496.06	2019.46	1987.46
Minimum patch size (hectares)	0.33	0.93	0.41	0.27

The latest land-use and land-cover trends detected in the Montado of Central Alentejo highlight change that is not only quantitative but more importantly qualitative (Godinho et al., 2016). Along with the continuous spatial decline and landscape fragmentation, a further process of change of equal importance for the potential provision of multiple public goods and ecosystem services has arisen over the past few years. This process is related to the structural change suffered by the Montado from a traditionally agro-silvo-pastoral system to a silvo-pastoral one, a change that is jointly driven by socio-demographic, economic, biophysical and even cultural changes in land-use practices and market dynamics (Godinho et al., 2014; Almeida et al., 2016).

Change such as those lately detected in the density, land-use and landscape heterogeneity and structural and ecological composition of the Montado in this region (Table 1) contribute to the important intensification/extensification debate (Pinto-Correia & Mascarenhas, 1999). This is ultimately also a valid argument to gain better understanding of the capacity for innovation in traditional and intrinsically complex and multi-functional land-use systems, such as agroforestry systems including the Portuguese Montado.

Key conflicts of use have been detected over the years between the Montado and several other land-uses. Some of the other land-uses with which the Montado conflicts include the Eucalyptus plantations that are aimed at the production of paper, medicines and soft-wood, and at the regulation flooding in plain areas, the expansion of extensive cereal and other herbaceous (e.g. maize) and ligneous (e.g. vines and olive trees) crops, and even in certain cases the abandonment of the underlying herbaceous layers of the Montado resulting in the progressive encroachment of the shrub vegetation strata (Godinho et al., 2014).

Such conflicts have all been considered of the upmost importance in diverse historic moments of the recent evolution of the Montado, and are reflected in the relevant legislation such as the already mentioned Regional Strategy for the Smart Specialisation of the Alentejo (2014) and the Decreto-lei de 30 de Junho 155/2004 on the Protection of Holm and Cork Oaks. In this sense, it is also worth mentioning that the Montado is considered at European level as a High

Nature Value farming system (Almeida et al., 2016; Paracchini et al., 2008), and thus object of special protection through tools such as Natura 2000 and the Habitats Directive. Despite this, between 2006 and 2012 (data from the CORINE Land Cover), about 1500 ha of Montado were substituted by olive groves in the Alentejo region alone.

The above diverse set of qualitative and quantitative changes since the mid-20th century have consequences and create challenges requiring a landscapes-systems approach. Furthermore, new societal demands value rural landscape functions related to sustainable resource management, landscape protection, leisure and recreation (Pinto-Correia & Breman, 2009; Primdahl & Swaffield, 2010). Latest emerging forms of collective actions, slowly arising in the montados of Central Alentejo, also support a landscape approach. From a spatial ecological perspective, it is clear from our analyses that the current fragmentation and structural change of an ecosystem of high nature value (Habitat Directive) is posing challenges (e.g. enhancing ecological connectivity), that need to be addressed beyond the farm level.

This may have been positively influenced by the fact that an extensive network of montado-based NATURA 2000 sites exists in our case study area, an initiative that is formally committed to contributing to the coordinated protection of this threatened and vulnerable land-use system. However, the transition towards a more effective multi-level governance model capable of supporting emerging forms of collective action is still only starting in the region, with issues such as the large size of private farm units and the small proportion of land under public or collective property potentially hampering alternative transition pathways.

Beyond 'public participation' and towards a co-construction of future landscapes

The management, planning and protection described in the European Landscape Convention (CE, 2000) requires an urgent move 'beyond public participation' (Muñoz-Rojas et al., 2015). A number of new tools, techniques and methods have been proposed and tested that might facilitate on-the-ground implementation of landscape-oriented strategies and actions by local stakeholders and other landscape users and beneficiaries. These tools are gradually moving away from printed spatial information as has been long employed in focus groups and participatory workshops for landscape planning, to the use of digital ICT tools that might support social learning, cooperation and innovation (Muñoz-Rojas et al., 2015). These tools include some aimed at use by experts (e.g. PPGIS) but others are useful for engaging social groups disenfranchised from planning and management, such as children (e.g. digital games).

We argue that a move towards more democratic and collaborative intervention regarding landscapes needs more than just sophisticated digital and ICT tools and techniques. Hence, to address such complex challenges, the DYNAMO research group at the Universidade de Évora have decided to engage in a transdisciplinary process using the core idea stated by Klein et al. (2001) - "*different academic disciplines working jointly with practitioners to solve real-world challenges*". Such a process of engagement draws directly on the long-term experience with, and recognition that the Institute of Mediterranean Agricultural and Environmental Sciences (www.icaam.uevora.pt), of which the DYNAMO group is part, holds with key local and regional stakeholders (McKee et al., 2015). The distinctiveness of how such a collaborative research process is being held by our group, and its potential to integrate from a landscapes-systems perspective is outlined in the following points:

i. The wide range of sub-systems (social, economic, cultural, biophysical and perceptive), scales and actions jointly driving change in the complex Montado landscape-system have all been addressed within a single research institution (http://www.en.icaam.uevora.pt/sobre/missao). The research group recognises that the Montado is a unique agroforestry system which has a complex social-ecological nature. Whilst most outputs have focused on the Montado as a production system, outputs related to governance and social aspects are increasing.
ii. Collaboration among researchers from different scientific disciplines and (sometimes conflicting) paradigms has been strongly encouraged, with more than 20 years of explicit research on the Montado system. The existence of a group such as DYNAMO, where social and natural, quantitative and qualitative, participatory and non-participatory, positivistic and post-positivistic approaches are embraced by individual members of the group (authors of this paper) within a shared landscapes-oriented approach, has proved key to implement truly interdisciplinary scientific approaches to the Montado.
iii. Along with the scientific and interdisciplinary construction of new knowledge, a long-term and continuous process of interaction with a vast range and number of local, regional and national stakeholders with relevance for the Montado in our case study area has been built over the past two decades. The continuity of such interaction has proved key in building confidence, trust and interest with groups of stakeholders that expands beyond the traditional set of farmers, land-managers and extension agents to include policy-makers and planners, consultants, financial agents, journalists, lobbyists with various and at times opposed interests, academics and researchers, conservationists, analysts, production chain agents and marketing professionals.
iv. Lastly (and of equal importance to the participation at multiple venues and events of a scientific, professional and participatory nature), a direct engagement with the local communities, agents and authorities that in Central Alentejo have a stake in the Montado has been pursued by members of the group. This is essential to facilitate the implementation of a common research agenda and subsequent process of knowledge co-construction.

Conclusion and next steps

Based on the findings achieved so far in our case study area of Central Alentejo, a series of conclusions can be drawn:

i. The Montado is indeed a complex socio-ecological system. As such it cannot be managed, planned or protected for purposes of sustainability and resilience without jointly considering the multiple social, economic, biophysical, cultural and perceptual drivers, spatial-temporal scales and sets of stakeholders that intervene in its dynamics.
ii. The most recent trends in the Montado of Central Alentejo indicate a decline in both its quantity and quality. The magnitude of such a decline is however not accurately documented in the official statistical and spatial information available. This is also true for the whole Portuguese Montado, and might also be the case for other agroforestry systems. Novel spatial and other ICT tools and methods of analysis are expected to improve documentation and facilitate realistic analysis of future sustainability and resilience.
iii. The aforementioned decline may have multiple negative social, economic and ecological consequences for the sustainability and resilience of the territories that have

traditionally been, currently are and will potentially be occupied by montados. Consequently this trend will likely have negative impacts on the quality of the populations inhabiting those territories. Thus, halting this trend is both a public and a private responsibility, and therefore tackling it necessarily demands a wider collaboration and knowledge co-construction between scientists, professionals, land-managers and a wide range of other stakeholders.

iv. In this paper we suggest that the ontological nature of landscapes as systems capable of encompassing all of the socio-economic, ecological, cultural, biophysical and perceptual aspects of land and land-use, render them as appropriate lenses through which to identify and implement innovations that enhance the montado. Furthermore, agroforestry landscapes, such as the montado, provide a good “test case” for action-oriented research schedules that progress beyond public participation to the co-construction of knowledge and actions. Such potential rests mainly on the spatial-temporal scale and capacity for triggering mutual cooperation and sense of belonging that inherently defines any landscape approach.

v. Despite the relative favourable potential for action-oriented research in landscape-systems approaches to the montado agroforestry system by the DYNAMO research team at the University of Évora, numerous challenges remain. These include: the need to critically revise and validate the spatial and statistical datasets currently available; the requirement to refine and fine tune an operational framework that spans the structural and perceived components of landscapes; and the opening of our schedule to other scientists and technicians operating in the production-oriented (e.g. agriculture and forestry) aspects of the montado in our case study area. An opportunity to take this forward is currently under way via a long-term schedule for knowledge co-construction among scientists and other stakeholders that we have termed ‘Tertulias do Montado’. We expect that valuable lessons will be drawn from this process for other similar agroforestry systems worldwide.

References

Almeida, M., Guerra, C., & Pinto-Correia, T. (2013). Unfolding relations between land cover and farm management: high nature value assessment in complex silvo-pastoral systems. Geografisk Tidskrifft-Danish Journal of Geography 113(2): 97-108.

Almeida, M., Azeda, C., Guiomar, N., & Pinto-Correia, T. (2016). The effects of grazing management in montado fragmentation and heterogeneity. Agroforestry Systems 90: 69-85.

Bugalho, M.N., Caldeira, M.C., Pereira, J.S., Aronson, J., & Pausas, J.G. (2011). Mediterranean cork oak savannas require human use to sustain biodiversity and ecosystem services. Frontiers in Ecology and the Environment 9: 278-286.

Carvalho-Ribeiro, S.M., Madeira, L., & Pinto-Correia, T. (2013). Developing comprehensive indicators for monitoring rural policy impacts on landscape in Alentejo, southern Portugal. Geografisk Tidsskrift-Danish Journal of Geography 113(2): 87-96.

Costa, A., Pereira, H., & Madeira, M. (2009). Landscape dynamics in endangered cork oak woodlands in Southwestern Portugal (1958-2005). Agroforestry Systems 77: 83-96.

Council of Europe (2000). European Landscape Convention. CETS No. 176, 9pp. http://conventions.coe.int/Treaty/Commun/QueVoulezVous.asp?NT=176andCM=8andCL=E
NG

Duckett, D., Feliciano, D., Martin-Ortega, J., & Muñoz-Rojas, J. (2016). Tackling wicked environmental problems: the discourse and its influence on praxis in Scotland. Landscape and Urban Planning. (In Press).

Ferraz-de-Oliveira, M.I., Azeda, C., & Pinto-Correia, T. (2016). Management of montados and dehesas for high nature value: an interdisciplinary pathway. Agroforestry Systems 90(1): 1-6.

Fragoso, R., Marques, C.A.F., Lucas, M.R., Martins, M.B., & Jorge, R.F. (2011). The economic effects of Common Agricultural Policy on Mediterranean montado/dehesa ecosystem. Journal of Policy Modeling 33(2): 311-327.

Godinho, S., Guiomar, N., Machado, R., Santos, P., Sá-Sousa, P., Fernandes, J.P., Neves, N. & Pinto-Correia, T. (2014). Assessment of environment, land management and spatial variables on recent changes in montado land cover in southern Portugal. Agroforestry Systems 90(1): 177-192.

Godinho, S., Gil, A., Guiomar, N., Neves, N., & Pinto-Correia, T. (2016). A remote sensing-based approach to estimating montado canopy density using the FCD model: a contribution to identifying HNV farmlands in southern Portugal. Agroforestry Systems 90: 23-34.

Guiomar, N., Godinho, S., Fernandes, PM., Machado, R., Neves, N., & Fernandes, J.P. (2015). Wildfire patterns and landscape changes in Mediterranean oak woodlands. Science of the Total Environment 536: 338-352.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits. Agroforestry Systems 76:1

McKee, A., Guimaraes, M.H., & Pinto-Correia, T. (2015). Social capital accumulation and the role of the researcher: an example of a transdisciplinary visioning process for the future of agriculture in Europe. Environmental Science and Policy 50: 88-99.

Muñoz-Rojas, J., Miller, D., Morrice, J., Papageorgiou, F., Mylonas, D., Tsemperlidou, M., Bell, S., Kuhlmann, F., Bruns, D., Mahne, T., Stojanovic, T., Del Alcazar, H., & Noguera, J. (2015). Going beyond public participation: an exploration of the role of ICT Tools to implement the European Landscape Convention (ELC) through challenge, learning, innovation and cooperation. In L. Miklos. The landscape, the European Landscape Convention and the Law. 17th International Symposium on Landscape and Landscape Ecology, 27-29 May 2015. Nitra, Slovakia.

Paracchini M.L., Petersen, J.E., Hoogevee, Y., Bamps, C., Burfield, I. & van Swaay, C. (2008). High nature value farmland in Europe: an estimate of the distribution patterns on the basis of land cover and biodiversity data. European Commission, Joint Research Centre, Institute for Environment and Sustainability. Luxembourg: Office for Official Publications of the European Communities.

Pedroli, B., & Pinto-Correia, T. (2006). Landscape - what's in it? European landscape research at a turning point – preface. Landscape Ecology 21(3): 313-313.

Pinto-Correia, T., & Breman, B. (2009). New roles for farming in a differentiated countryside: the Portuguese example. Regional Environmental Change (3): 143-152.

Pinto-Correia, T., Gustavsson, R., & Pirnat, J. (2006). Bridging the gap between centrally defined policies and local decisions - towards more sensitive and creative rural landscape management. Landscape Ecology 21(3):333-346.

Pinto-Correia, & T., Kristensen, L. (2013). Linking research to practice: the landscape as the basis for integrating social and ecological perspectives of the rural. Landscape and Urban Planning 120: 248-256.

Pinto-Correia, T., & Mascarenhas, J. (1999). Contribution to the extensification/intensification debate: new trends in the Portuguese Montado. Landscape and Urban Planning 46 (1/3): 125-131.

Pinto-Correia T., Ribeiro N., & Potes, J.M. (2013). Livro Verde dos Montados. MONTADO/DEHESA: um sistema agro-silvo pastoril único na EUROPA. Apresentação Pública do Livro Verde dos Montados, Feira do Montado, Portel, 29 Novembro 2013.

Pinto-Correia, T., Ribeiro, N., & Sa-Sousa, P. (2011). Introducing the montado, the cork and holm oak agroforestry system of Southern Portugal. Agroforestry Systems 82 (2): 99-104.

Power, A.G (2010). Ecosystem services and agriculture: trade-offs and synergies. Philosophical Transactions of the Royal Society B 365 (1554): 1959-1971.

Primdahl, J., & Swafield, S. (2010). Globalisation and Agricultural Landscapes. Change Patterns and Policy trends in Developed Countries. Cambridge: Cambridge University Press.

Sa-Sousa, P. (2014). The Portuguese Montado: conciliating ecological values with human demands within a dynamic agroforestry system. Annals of Forest Science 71(1): 1-3.

Satake, A., Rudel, T.M., & Onuma, A. (2008). Scale mismatches and their ecological and economic effects on landscapes: a spatially explicit model. Global Environmental Change 18: 768-775.

Spurgeon, D. (1979). Agroforestry. New hope for subsistence farmers. Nature 280: 533-534.

Surova, D., & Pinto-Correia, T. (2008). Use and assessment of the 'new' rural functions by land users and landowners of the Montado in southern Portugal. Outlook on Agriculture 38 (2): 189-194.

Thompson Klein, J., Grossenbacher-Mansuy, W., Häberli, R., Bill, A., Scholz, R.W., & Welti, M. (Eds.) (2001). Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society. An Effective Way for Managing Complexity. Birkhäuser Ed.