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Quantification of agroforestry systems in the Czech Republic

MASTER'S THESIS

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Thesis title: **Quantification of agroforestry systems in the Czech Republic**

Objectives of thesis: The objective of the thesis is to assess the extent of agroforestry systems in the Czech Republic, their characterization and evaluation. Specific objective is to make a map of localities where thouse agroforestry systems are located.

Methodology: First part of the thesis will be a short introduction about agroforestry systems in Europe and definition of similar agroforestry systems found in the Czech Republic. Second part will be devouted to data filtering and processing. Data will be taken from the EU survey called LUCAS (Land Use/Cover Area frame statistical Survey). After that, these data will be evaluated based on the real situation. Selected localities will be visited and checked. Data filtering and processing will be based on the article from Herder et al. (2017). Third part will be actual map of agroforestry systems in the Czech Republic with predefined classes of agroforestry systems in ArcGis. The last part will be comparison of found and checked agroforestry systems with those found and evaluated by Zelba, 2016.

The proposed extent of the thesis:	40-60 pages
Keywords:	Czech Republic, agroforestry, agroforestry systems

Recommended information sources:

1. den Herder M, Moreno G, Mosquera-Losada RM, Palma JHN, Sidiropoulou A, Santiago Freijanes JJ, Crous-Duran J, Paulo JA, Tomé M, Pantera A, Papanastasis VP, Mantzanas K, Pachana P, Papadopoulos A, Plieninger T, Paul J. Burgess PJ. 2017. Current extent and stratification of agroforestry in the European Union. Agriculture, Ecosystems & Environment 241: 121-132
2. MOSQUERA-LOSADA, M R. -- MCADAM, J. -- RIGUEIRO-RODRÍGUES, A. *Agroforestry in Europe : Current Status and Future Prospects.* New York: Springer, 2008. ISBN 9781402082719.
3. Zelba O. 2016. Agroforestry in Czech Republic. MSc. Thesis, Czech University of Life Sciences Prague, Czech Republic. 42 pp.

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doc. Ing. Bohdan Lojka, Ph.D.
Head of department

Declaration

I hereby declare that I have done thesis entitled *Quantification of agroforestry systems in the Czech Republic* independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 27th April 2018

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Radim Lainka

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Abstract

Agroforestry in Europe has a long tradition. It has been researched, described and categorized several times for various reasons. Although, only one time it was researched with the main aim to quantify and map some agroforestry systems (AFS) in Europe with the help of modern methods. This study followed that researched, but only at national scale. This MSc Thesis aimed to find AFS in the Czech Republic and make a map of them. To localize them, datasets from European Union surveys of Land Use and Cover Area Frame Survey (LUCAS) were used. The thesis tried out the method to evaluate all the LUCAS points from all the available LUCAS surveys undertaken in the Czech Republic according to the predefined sets of criteria's in the ArcMap 10.4.1., part of ArcGIS software. Then, the selected LUCAS points were assigned to the individual AFS, Livestock agroforestry or High value tree agroforestry, according to the applied set of criteria's. Later, all the AFS were projected into the map of all the AFS in the Czech Republic in the ArcMap 10.4.1. To estimate the current extent of the AFS in the Czech Republic, those points were used, too. Next step was to evaluate ten randomly selected AFS in the terrain and take a photo documentation of them. At the end, these points were linked to the Land Parcel Identification System (LPIS) or to the cadastre of real estates, if it these AFS were not localized primarily in the LPIS. The main aim of this step was to find out the data about current Land use, size of parcels and some additional information. In total, it was found twenty-five AFS in the Czech Republic. Twenty-One Livestock agroforestry systems and four High value tree agroforestry systems. The total extent of AFS in the Czech Republic was estimated to be 35,751 ha. Fifteen parcels with AFS (60%) were identified to be permanent grasslands. Four parcels with AFS (16%) were identified to be other areas. Three parcels with AFS were identified to be forest lands. Another three parcels were identified to be agricultural lands. Only one parcel was identified to be orchard.

Keywords: LUCAS, LPIS, ArcGis, EU, trees, AFS, silvopastoral systems

Abstrakt:

Agrolesnictví v Evropě má dlouhou tradici. Bylo několikrát z různých důvodů prozkoumáno, popsáno a kategorizováno. S cílem kvantifikovat a zmapovat agrolesnické systémy (ALS) v Evropě bylo zkoumáno jen jednou pomocí moderních metod. Tato práce je pokračováním této studie, ale pouze v národním měřítku. Úkolem této diplomové práce bylo najít ALS v České republice a vytvořit mapu těchto systémů. Pro jejich lokalizaci byly použity datové sady z průzkumů Evropské unie Land Use and Cover Area Frame Survey (LUCAS). V této práci byla vyzkoušena metoda vyhodnocení všech bodů LUCAS. Byly v ní zahrnuty všechny dostupné průzkumy provedené v České republice z let 2009, 2012 a 2015, podle předdefinovaných souborů kritérií v ArcMap 10.4.1., jež je součástí softwaru ArcGIS. Následně byly vybrané body z databází LUCAS přiděleny k jednotlivým ALS, Livestock agroforestry nebo High value tree agroforestry podle použitého souboru kritérií. Postupně byly v programu ArcMap 10.4.1 zobrazeny všechny systémy AFS, ze kterých byla vytvořena mapa všech ALS České republiky. Tyto body byly použity pro odhad rozsahu současných ALS v České republice. Dalším krokem bylo vyhodnocení deseti náhodně vybraných ALS v terénu, včetně fotodokumentace. Nakonec byly tyto body propojeny s veřejným registrem půdy (LPIS) nebo s katastrem nemovitostí v případě jejich nenalezení v LPIS. Hlavním cílem tohoto kroku bylo zjistit údaje o aktuálním využití těchto parcel, velikosti parcel a některých dalších informacích. Celkem bylo v České republice zjištěno pětadvacet ALS. Dvacet jedna systémů tzv. Livestock agroforestry a čtyři tzv. High value tree agroforestry. Celkový rozsah ALS v České republice byl odhadnut na 35,751 hektarů. Patnáct parcel s ALS (60%) bylo identifikováno jako trvalé travní porosty. Čtyři parcely s AFS (16%) byly identifikovány jako ostatní plochy. Tři parcely s AFS byly identifikovány jako lesní pozemky. Další tři parcely jako zemědělské pozemky, pouze jedna jako sad.

Klíčová slova: LUCAS, LPIS, ArcGIS, EU, stromy, ALS, silvopastorální systémy

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List of the abbreviations

AF: Agroforestry

CLC: Corine Land Cover

EU: European Union

EUROSTAT: statistical office of the European Union situated in Luxembourg

ETRS-89: European Terrestrial Reference System 1989

FAO: The Food and Agriculture Organization of the United Nations

GIS: Geographic Information System

ICRAF: The World Agroforestry Centre

LPIS: Land Parcel Identification System

LUCAS: Land Use and Cover Frame Area Survey

s.r.o.: sdružení s ručením omezeným

TOF: Trees outside the forest

UAA: utilised agricultural area

USA: United States of America

WGS1984: World Geodetic System 1984

WP: work-package

1. Introduction

Various authors tried to define agroforestry system practices. One of the most common definitions of these practices was found by Nair (1993), as practices which involve: “the deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land”. It draws attention in the late 1970s, when the international scientific community recognized its potential benefits in the tropics and accept it as practice to be further developed and studied by science. Nowadays, administrative systems of many national governments from Europe acknowledge only agriculture or forestry as rightful land use systems and agroforestry systems supposed to be only remnants of the past (Mosquera-Losada et al. 2009). Apart from forestry and agriculture, agroforestry practices are more diverse with higher complexity (Nair et al., 2008). Multi-functionality of agroforestry systems is well known between experts. In relation with a wider ecosystems perspective could be a driving force for enhancement of social well-being in the rural areas (Mosquera-Losada et al. 2009). Among other benefits of agroforestry systems belong better use of resources in a spatial and temporal scale. Further on, there is enhancement of environment quality through reduction in nutrient losses from agricultural land, increased carbon sequestration, enhancement of biodiversity, reduced soil losses and management fire risk in specific areas (Mosquera-Losada et al. 2009; Nair et al. 2012).

However, there is need to recreate (merge and consolidate) some definitions of agroforestry systems to make it simpler for further use and development. It needs to be done, to be applicable for quantification of these systems and make some space for them in the legislation of European states, to keep up to date knowledge about current extent and state of existing agroforestry systems. Similarly, as it is done for forestry and agriculture systems (Mosquera-Losada et al. 2009). European Union defined agroforestry in the 2013 by the regulation No. 1305/2013. It is standard definition to get subsidies (EU 2013): “Agroforestry systems means land use systems in which trees are grown in combination with agriculture on the same land. The minimum and maximum number of trees per ha shall be determined by the Member States taking account of local pedo-climatic and environmental conditions, forestry species and the need to ensure sustainable agricultural use of the land.”

Although agroforestry is considered as mostly forgotten phenomenon in the Czech Republic, there is still chance to restore these land-use systems at least partially. Historical data showed us that some of the agroforestry systems were practiced in the past within the territory of our country (Molnárová et al. 2008; Krčmářová and Jeleček 2016). According to our current knowledge, the first agroforestry plots were reported in the 1689. Cropland with fruit trees, and meadows, and pastures with either fruit trees or timber trees were common part of Czech countryside in the mid-nineteenth century, but did not survived the industrialization of agriculture (Krčmářová and Jeleček 2016). Only a few theoretical estimations related to the silvopastoral systems were done quite recently (Herzog 1998; Plieninger et al. 2015). But various agroforestry systems still exist, either as relicts of traditional agroforestry systems or newly developed agroforestry practices. Currently we do not have any relevant estimation of the extent and type of agroforestry systems in the Czech Republic. So far there were no inventories, neither specialized surveys dealing with specific land-use practices such as agroforestry. Therefore, the main objective of this study was to estimate and quantify the extent of agroforestry systems in the Czech Republic. The latest study aimed on the quantification of the agroforestry systems in the European Union proofed that there are some agroforestry systems in my country (den Herder et al. 2017).

2. Literature review

2.1 Definitions of Agroforestry

The first definition for scientific world of "agroforestry" was made in 1977, to specify the synthesis of trees with agriculture by Lundgren (1982), and it was suggested as follows:

"*A collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) or livestock, in a spatial arrangement, a rotation, or both; there are usually both ecological and economic interactions between the trees and other components of the system*"

There are several definitions of agroforestry or better agroforestry systems in use. Burgess at al. (2015) defined agroforestry as: "the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions", similarly as MacDicken and Vegara (1990).

Probably, the first agroforestry definition in my homeland was found out by an association called:" *Český spolek pro agrolesnictví*". The main target was to develop and promoteagroforestry practices in the Czech Republic. They defined agroforestry as follows (translated to English):

"*Agroforestry is management of agricultural or forest land that combines growing perennials with some form of agricultural production, spatially or temporally. The components of agroforestry system (trees, crops, animals, or others) have to be cultivated with productive and/or environmental goals*."

The second definition for agroforestry in the Czech Republic was found out by Zelba (2016). He defined agroforestry systems for applying financial support (subsidies) as follows:

"

- *There are at least two plant species that interact together biologically and were both deliberately planted on one agricultural land unit and all of the species have a single owner or manager.*
- *At least one of those species is a woody perennial. The crown cover of the woody perennials have to be at least 10% of the complete area, or able to reach that percentage in maturity. The complete are of the plot needs to be above 1 ha.*
- *At least one of the species that is not a woody perennial is managed for forage, annual, or perennial crop production. The forage crops can be either grazed directly or managed as cut-and-carry.* "

However, there is still no single definition of agroforestry or agroforestry systems in the Czech Republic defined by the law.

Thus, agroforestry could include quite many either agricultural (e.g. sawing) or even forestry practices (e.g. pruning) that could be structurally very different, with the major condition that they include trees. Agroforestry can be distinguished between certain amounts of practices that together form unique transitions between silviculture and agriculture. The most common practices were described by Association for Temperate Agroforestry (AFTA 1997) and later by Alavapati and Nair (2001). According to them, there are five essential types of agroforestry practices in temperate areas, i.e. windbreaks, alley cropping, silvopasture, riparian buffers and forest farming (edge of agroforestry practices). This classification was made in America, specifically after their major agroforestry forms. Thus, it does not fit our conditions in Europe so well. Nevertheless, this classification scheme is still legitimate, but it was modified to cover European conditions (Table 1). It includes silvoarable agroforestry, forest farming, riparian buffer strips, silvopasture, improved fallow (historical practice), multipurpose trees, and silvopasture (Mosquera-Losada et al. 2009).

Table 1. Agroforestry practices in Europe.

Agroforestry practices	**Brief description**
Silvoarable agroforestry	Widely spaced trees inter-cropped with annual or perennial crops. It comprises alley cropping, scattered trees and line belts
Forest farming	Forested areas used for production or harvest of natural standing specialty crops for medicinal, ornamental or culinary uses
Riparian buffer strips	Strips of perennial vegetation (tree/shrub/grass) natural or planted between croplands/pastures and water sources such as streams, lakes, wetlands, and ponds to protect water quality
Improved fallow (historical practice)	Fast growing, preferably leguminous woody species planted during fallow phase of shifting cultivation; the woody species improve soil fertility and may yield economic products
Multipurpose trees	Fruit and other trees randomly or systematically planted in cropland or pasture for the purpose of providing fruit, fuelwood, fodder and timber, among other services, on farms or rangelands
Silvopasture	Combining trees with forage and animal production. It comprises forest or woodland grazing and open forest trees

Source: Modified from Association for Temperate Agroforestry (AFTA) 1997; Alavapati and Nair 1994; Alavapati et al. 2004), taken from the book Agroforestry in Europe: Current Status and Future Prospects (Mosquera-Losada et al. 2009)

The silvoarable agroforestry is further divided into three major practices used currently in Europe: alley cropping, scattered trees on arable land and linear belts of trees (Table 2).

Table 2. Major practices of silvoarable agroforestry in Europe.

Practices	**Brief description**
Alley cropping	i.e. trees planted in single or grouped rows within agricultural or horticultural fields with crops growth in the wide alleys between the tree rows
Scattered trees	At low density (not in rows) with an annual cropping pattern, vegetables or fodder production (to make silage or hay), but also perennial crops which are harvested every few years (e.g. energy crops)
Line belts	Hedgerows, shelterbelts, windbreaks and forest belts.

Source: Mosquera-Losada et al. (2009). Belts are tree rows distributed around farms and, together with the riparian systems are classified as "trees outside forest" in European statistics (MCPFE 2003).

The silvopasture agroforestry is further divided into two major practices used currently in Europe: forest of woodland grazing and open forest trees (Table 3). However, it is obvious that this division is more appropriate for Mediterranean region, not really fitting to Northern part of Europe as forest grazing is usually and historically prohibited.

Table 3. Practices of silvopasture agroforestry in Europe.

Practices	**Brief description**
Forest or woodland grazing	Forestry production is promoted (high density stands, natural forests), primary combined with wild, local or autochthonous breeds of animals
Open forest trees	Low density stand, recently afforested/reforested areas, with wild/domestic animals

Source: Mosquera-Losada et al. 2009

These classification schemes served as background for more systematic approach of agroforestry on the European scale that was made by in the project AGFORWARD with its aim to stratify and quantify agroforestry in the countries of European Union. The AGFORWARD project delimited agroforestry into four core areas (Figure 1).

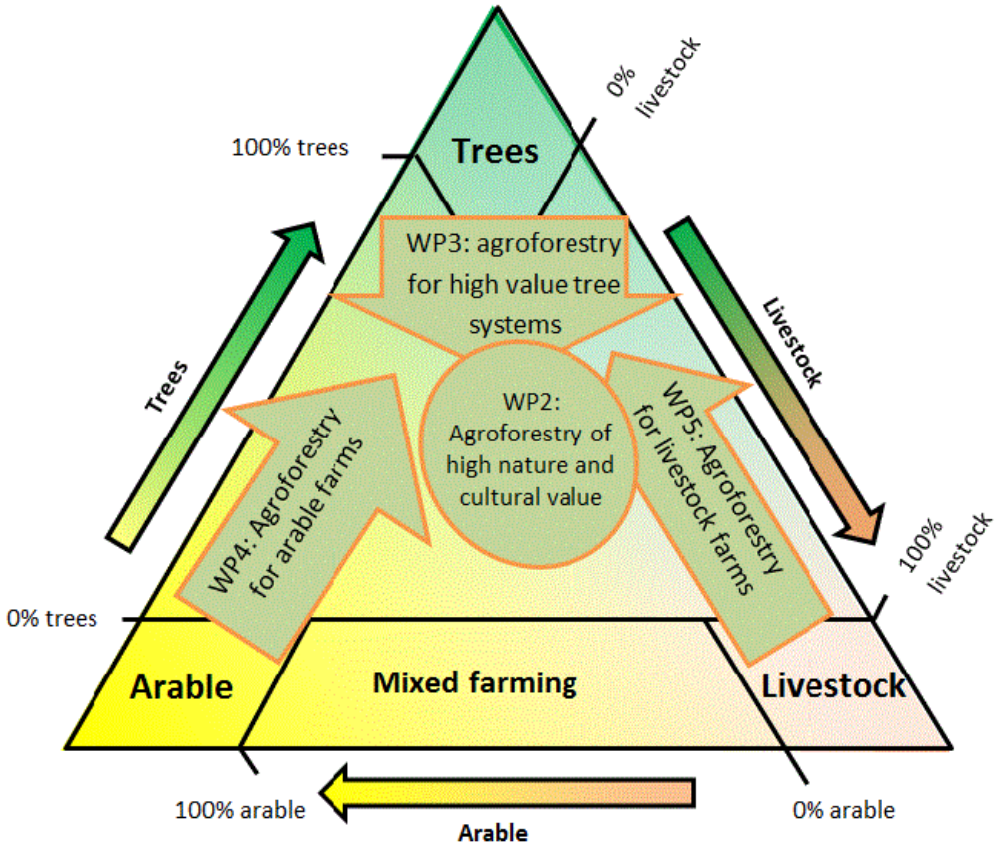

Figure 1. The AGFORWARD project schema, taken from den Herder et al. (2015).

These four core areas are: existing agroforestry practices of high nature and cultural value (HNCV) (WP2), integrating livestock and crops into high value tree systems (WP3), agroforestry for arable farms (WP4) and agroforestry for livestock farms (WP5).

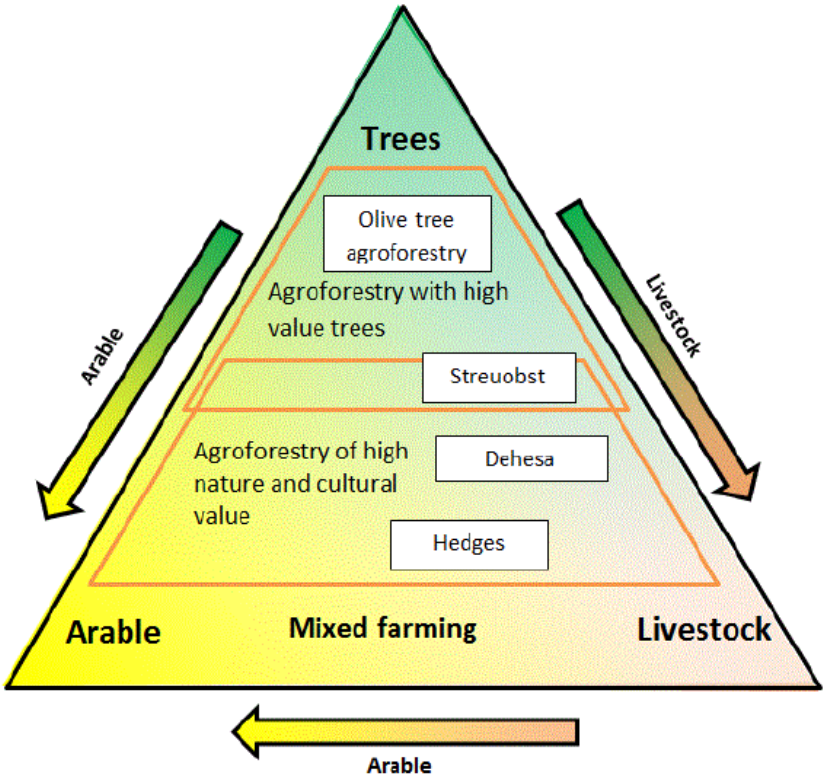

Figure 2. Agroforestry practices that overlapped predefined WP categories, taken from den Herder et al. (2015).

However, these categories (systems) consist some transient agroforestry practices (Figure 2) that overlapped temporary or spatially these categories. Namely for example *Streuobst* and *Dehesa* (den Herder et al. 2015). These categories with their agroforestry practices are explained in the orchard (Figure 3) and in the following chapters (2.2 up to 2.6).

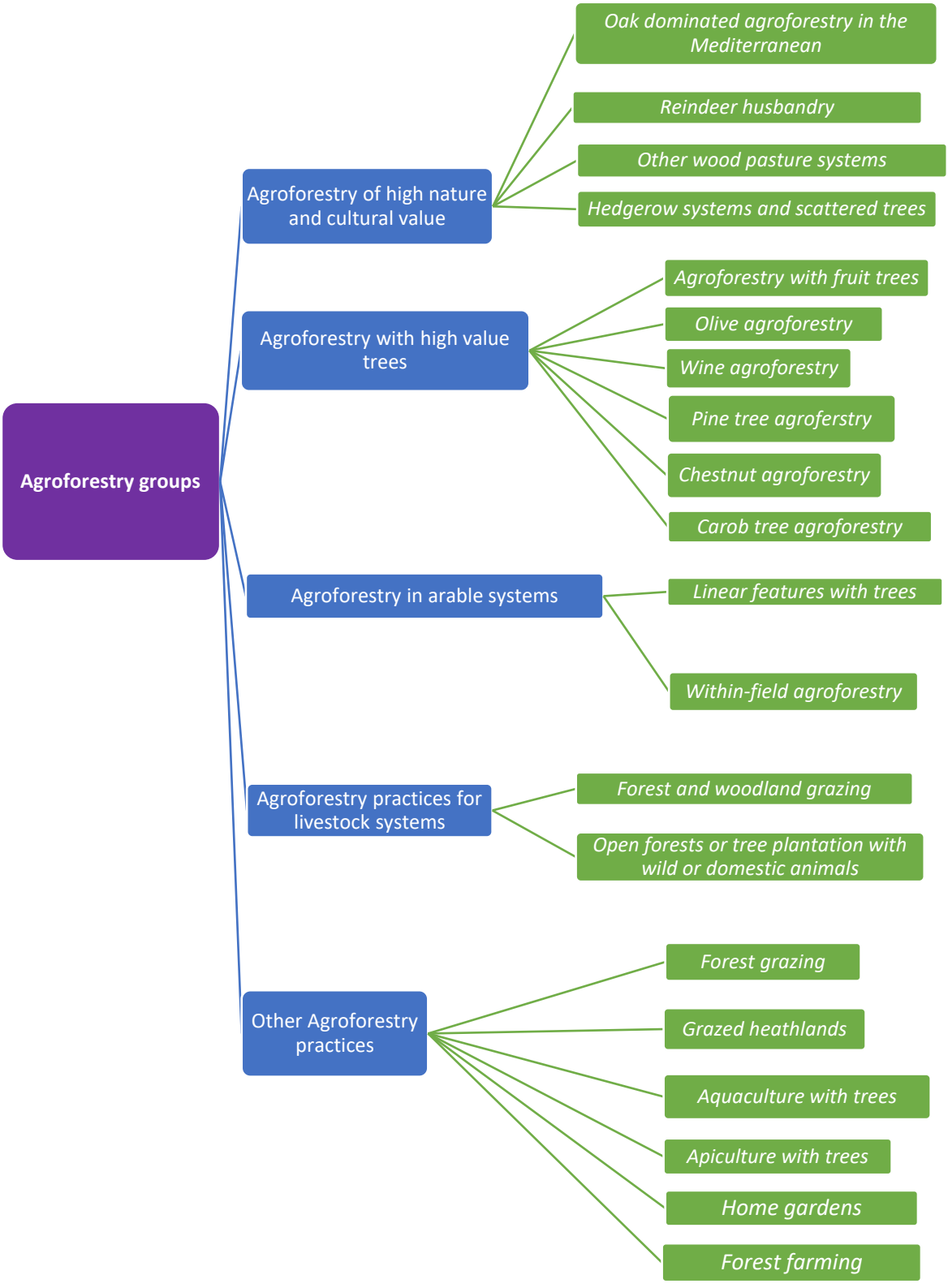

Figure 3. Groups of agroforestry systems of Europe delimited by den Herder et al. (2015).

2.2 Agroforestry of high nature and/or cultural value

Most traditional European agroforestry systems combined livestock farming with the cultivation of various tree species to produce some secondary products like fruit, firewood, timber, fodder or to provide shelter for animals (Mosquerada-Losada et al. 2012; Plieninger et al. 2015). Many of them are found in the marginal regions where the orography, soil fertility and climate does not meet the conditions for intensive agriculture (Plieninger et al. 2015). Although, these agroforestry systems are known that they don't rely on high quantity of external inputs, frequently retain a high proportion of semi-natural habitats and trees. Thus, they are predefined to be the agroforestry systems of high nature value (Andersen et al. 2003). Theses local management practices gradually resulted into specific "cultural landscapes" adapted to its unique climatic and geographical conditions. This process that changes the "natural" environments to "cultural landscapes" contributed to the world biodiversity heritage a lot (Hartel and Pleininger 2014). And those agroforestry systems were defined as the Agroforestry of high nature and cultural value. It is simply defined as systems that ingrate woody vegetation with livestock and/or crops and in the same time are valued for their biodiversity and their cultural heritage (Moreno et al. 2017).

Historically, this group of agroforestry systems was established on the two separate classifications. The first was linked to the high nature value (HNV) grouping and the second one was linked to the so-called Traditional Agricultural Landscapes (TAL) (den Herder et al. 2015).

HNV concept was made by the European Environment Agency (Parachini et al. 2006). Main aim was to link biodiversity and environmental aspects regarding agriculture in Europe. There are some examples where specialized farming practices and systems can back high biodiversity levels within this concept (Pointereau et al. 2007). For e.g. the *dehesas* and *montados* agroforestry systems in Iberian Peninsula (den Herder et al. 2015). Parachini et al. (2006) identifies three types of HNV farmland: 1) farmland with a high proportion of semi-natural vegetation, 2) farmland with a mosaic of low intensity agriculture and natural and structural elements, such as field margins, stone walls, patches of woodland or scrub, and small rivers, and 3) farmland supporting rare species or a high proportion of European or world populations. Typical agroforestry systems that retain

relatively high natural and cultural values apart from the *dehesas* (Spain) and *montados* (Portugal) (den Herder et al. 2015).

TAL concept is actual classification with some parallels concerning HNV. Apart from HNV parallels, the TAL target farmlands that hold "traditional" forms of farming (Cooper et al., 2007). Such as production diversification and a traditional or locally adapted management approach, for e.g. in Castile-La Mancha, Spain's cereal-sheep system (Caballero and Gíl 2009).

This group is dominated by woody pastures tree-land systems with animals or wildlife that are regularly grazing the land. These traditional systems are multipurpose, animals provide fertilization and control tree encroachment (Bergmeier et al. 2010). As these systems were historically quite widespread in Europe, there are plenty regional or local terms (*Streuobst, Bacage, Shibliak* etc.) related to wood-pasture types (Bergmeier et al. 2010 and Opperman et al. 2012).

Further on, this group is divided to four subcategories. The first one is *oak dominated agroforestry in the Mediterranean*, second is *other wood pasture systems*, third is *hedgerow systems and scattered trees*, and the fourth is *reindeer husbandry* (den Herder et al. 2015).

2.2.1 Oak dominated agroforestry in the Mediterranean

These systems of land use are being practised up to 4,500 years. These systems spread on a variety of habitats, from open pastures and meadows to closed canopy forest with the largest share in the Mediterranean region (Stevenson and Harrison 1992). The origin of *dehesas* and *montados* was in the clearing of natural forests and establishment of multipurpose open woodlands. *Dehesas* are sources of feeding (browsing and forage) for both domesticated and wild animals at the times of early summer droughts. Apart from these functions, it was proved that these entities found shade there and it helped to reduce the fire accidents. Several of them blend more agroforestry systems together, such as silvopasture, silvoarable and multipurpose trees in unique ways. Several practices formed *dehesas* and *montados*, such as livestock keeping (cattle, sheep, goats, pigs and horses) in low densities, cereal production, cork and firewood harvesting, and wildlife hunting. Although *dehesa* was artificial (man-made) landscape, it was confirmed the most biodiverse landscape in Europe (Moreno and Pulido2009). Later, these systems were

qualified as natural habitats to be preserved for the future under the EU Habitat Directive (Castro 2009; Moreno and Pulido 2009). Actual extent of *dehesas* in Spain is about 3.6 million ha, whereas the extent of *montados* is 1.1 million ha in Portugal (Ministerio de Agricultura, Alimentación y Medio Ambiente; Inventário Florestal Nacional 2013a).

Dehesas are well known for acorn production from trees like holm oak (*Quercus ilex* L.) and cork oak (*Quercus suber* L.) Theses acorns served as cheap sources of food to feed the animals like pigs, especially during the times where there is no other fodder (grass) accessible (Cañellas et al. 2007). This problem is recognized almost over the whole Mediterranean region, thus the importance of multipurpose or fodder trees and shrubs is essential as temporary food source for animals (Dupraz 1999). Other traditional agroforestry practices, where pigs are involved is in north-west Spain. There, pigs are grazed in the chestnut woodlands, and during the fattening period are feeding the chestnuts (*montanera*). This practice is connected primarily with the autochthonous Galician pig breed (Celtic breed) (Mosquera-Losada et al. 2009).

2.2.2 Other wood pasture systems

These systems were described in other parts of Europe. In central, eastern (north part of Slovenia, Southern Transylvania - Romania), western Europe (Ireland, northern Italy, United Kingdom) and northern (eastern Finland) Europe, where the trees main function lied in the provision of shelter for livestock (cattle and sheep) during the winter (den Herder et al. 2015).

Well described was the wood pastures and parklands in the UK. The composition of these woodland parklands varies from lowland beech (*Fagus sylvatica*) and yew (*Taxus baccata*) woodland, lowland mixed deciduous woodland, upland mixed ash (*Fraxinus excelsior*) woods, upland oak (*Quercus* spp.) wood, wet woodland, wood pasture, up to parkland. The most frequent trees are oak, beech and hornbeam (*Carpinus betulus*) and ash. One of the largest remaining areas of wood-pasture in temperate Europe is probably the New Forest in southern England, with more than 3,000 ha of woodland grazed by ponies, deer, cattle and pigs (Smith 2010).

2.2.3 Hedgerow systems and scattered trees

It is example, where agroforestry is practiced at a farm or even at landscape level. The clear cases were studied in France and UK – trees integrated with farming systems. The width of hedges differs in each country. Quite wide hedges (larger than 16 m width) were reported from England, Scotland, and Wales (Forest Commission 2001a; Forest Commission 2001b; Forest Commission 2001c).

2.2.4 Reindeer husbandry

It is practiced only on boreal and subarctic wood-pastures. It was recognized as crucial part of lifestyle of various indigenous peoples in Nordic countries (Finland, Sweden and Norway) with great economic and cultural implications for them. The most common trees are hairy birch (*Betula pubescens*) and Scotch pine (*Pinus sylvestris*) (Bergmeier et al. 2010).

2.3 Agroforestry with high value trees

Definition of this system is the same as for multipurpose trees. Multipurpose trees may be fruit trees and other trees or another trees systematically or randomly planted in cropland or pasture for the multiple purposes. Ranging from fruit for human and animal consumption, fuelwood, fodder and timber etc (Mosquera-Losada et al., 2009). Wood-based products include timber, poles, paper fibre, firewood, and charcoal. Non-timber products are mainly fruits and sometimes leaves (as flavouring or for tannins) and the bark, for example cork (construction, cork stoppers etc.) (den Herder et al. 2015).

This group of agroforestry systems is focused on multipurpose trees like fruit trees (eq. apple, pear, olive, carob, almond etc.) and valuable timber species (eq. wild cherry) combined with traditional production (crop or animal) (Table 4).

This group included six subcategories: *Agroforestry with fruit trees*, *Olive agroforestry*, *Vine agroforestry*, *Pine tree agroforestry*, and *Carob tree agroforestry*.

Table 4. High value trees and their functions.

High value trees	**Functions**
Apple (*Malus*), peach *(Prunus*) and pear (*Pyrus*), apricot (*Prunus*), plum (*Prunus*), quince (*Cydonia*) and fig (*Ficus*)	Fruits
Olive tree (*Olea europea* L.)	Olives, olive oil, timber, firewood
Wild cherry (Prunus avium)	Fruit, timber, the gum from bark
Walnut (*Juglans*)	Nuts, timber, firewood
Italian stone pine (*Pinus pinea*)	Pine nuts, timber, firewood, resin, woodchip
Chestnut (*Castanea*)	Nuts, fodder, timber, tannin, firewood
Holm oak (*Quercus ilex*)	Cork, timber, acorns, leaves, tannin
Carob (*Ceratonia siliqua*)	Dried pods, animal fodder etc.

Source: den Herder et al. (2015)

2.3.1 Agroforestry with fruit trees

This subcategory is characteristic by fruit production systems interconnected with the grazing of livestock or intercropped crops. Silvoarable systems with the focused-on fruit and nut production covered large areas of central Europe in the past (Smith 2010). There are some countries, where this kind of agroforestry remained. For eq. about 18,000ha of almond trees intercropped with cereals in Sicily, and about 10,200 ha of fig trees intercropped with cereals in Crete and the Aegean islands (Eichhorn et al. 2006).

Different names were coined to this agroforestry practice in European countries, "*Streuobst*" in Germany, "*prés vergers*" in France, "*fruit-tree meadows*" and "*orchards*" in England. Typical agroforestry system of this subcategory is *Streuobst*. This traditional agroforestry system survived in continental and central Europe. It was defined as tall trees of different types, varieties and ages of fruit, scattered in croplands, meadows and pastures. The tree density varies usually from 20 to 100 trees per ha. Apart from the definition, fruit tree alleys along streets were regarded as a form of *Streuobst*, too. However, fruit trees in gardens were not considered as streuobst (Herzog 1998). There is certain lack of data to fully estimate this practice in the Europe. On the other hand, it was estimated that this practice is still taking place on around one million ha of "*Streuobst*"

in eleven European countries (Herzog 2000). Some areas with Streuobst practice were also found in the Czech Republic, with the estimation of about 9,277 ha (Herzog 1998).

2.3.2 Olive agroforestry

The most commonly planted evergreen species that formed agrosilvopastoral systems in the Mediterranean region is the olive tree (*Olea europea* L.) (Papanastasis et al. 2009). Olives are planted there for economic and socio-cultural reasons. It is estimated that 98% of the world´s olive production is produced in this region (Kiritsakis1998; Papanastasis et al. 2009). The olive agroforestry area in Greece was estimated to be about 124,311 ha (Papanastasis et al. 2009). Olive trees are usually intercropped with cereals, vegetables and fodder crops (Schultz et al. 1987).

2.3.3 Vine agroforestry

Different crops and woods are used in combination with vine (*Vitis vinifera*), e.g. in northern Portugal. There, woods (*Quercus lusitanica*, *Ulmus* spp. and *Prunus* spp.) are used as living trellis to support fast growing vine in vineyards. Crops, such as maize and varieties of vegetables are commonly intercropped in the free spaces among the grape rows (Altieri&Nicholls 2002).

2.3.4 Pine tree agroforestry

This agroforestry system was largely established in Portugal and Italy (Inventário Florestal Nacional 2013b; Pardini 2009). The largest area of pine agroforestry with stone pine (*Pinus pinea*) was measured in Portugal, about 173,716 ha (Inventário Florestal Nacional 2013b**).** It is concentrated in just two regions (Alentejo and Ribatejo region) (Anuario Vegetal 2006). There, pine nuts from cones are the most valuated product out of this system (Anuario Vegetal 2006).

2.3.5 Chestnut agroforestry

It is based on the variety of products (timber, nut and tannin) from chestnut tree (*Castanea sativa* Mill.), it was recognized as one of the multipurpose species. Italy, France, southern Switzerland, Spain, Portugal and Greece are countries with long and steady chestnut tradition, it has been cultivated for centuries (Conedera et al. 2014).

The last subcategory is coined to *carob tree agroforestry*. Carob (*Ceratonia siliqua* L.) is another multipurpose tree that is used as fodder and pods are used as substitute for cacao. It is mostly intercropped with cereals and fodder legumes. This system was found in Mediterranean countries, particularly Spain, Portugal, Italy, Greece, Malta, Cyprus, Morocco and Turkey (Anuario Vegetal 2006; Eichhorn et al. 2006).

2.4 Agroforestry in arable systems

This group of systems devote to the integrating of trees into arable systems. There is hidden potential to integrate trees and crops in the profitable way, whilst reduce soil erosion and nitrate leaching in same time, estimated on 40% of the European arable land (Reisner et al. 2007). On this basis, the overall landscape biodiversity levels could be raised with the help of agroforestry systems (Palma et al. 2007).

Integration of trees to arable systems can be practically done in several ways that ranges from alley cropping, buffer strips, windbreaks, hedgerows, up to shelterbelts. These practices are found in the Europe, nevertheless, there are no reliable data sources about the actual extent of these agroforestry practices (den Herder et al. 2015).

Within this system there were identified two subcategories, *linear features with trees* and *within-field agroforestry* (den Herder et al. 2015). The first subcategories were devoted to buffer strips, windbreaks, and hedgerows (Schoeneberger et al. 2012). Apart from productive functions, complex of landscape features can be enhanced within these agroforestry practices (landscape aesthetics, biodiversity increase, and self-regulative environmental services) (den Herder et al. 2015).

2.4.1 Linear features with trees

Buffer strips or better riparian buffer strips consists of perennial vegetation of trees, shrubs and grasses that are planted between croplands/pastures and water sources such as streams, lakes, wetlands, and ponds to protect water quality. There and over the Europe are frequently found along water courses and some of them are remnants of former river plains forests with willows (*Salix* spp.), alder (*Alnusglutinosa* (L.) Gartn.) and variety of hardwood trees (*Fraxinus excelsior* L., *Ulmus* spp., Acer spp., *Quercus robur* L.). They provide protection of water bodies against sedimentation, soil erosion on

adjacent agricultural lands, against nitrate contamination, regulate light and temperature of the rivers, acting as green filters reducing eutrophication processes, stabilise river banks, food and cover for aquatic fauna and amphibian, and serving as corridors for flora and fauna (Jongman and Kristiansen, 2001; Jongman and Kamphorst 2002; Osborne and Kovacic 1993; Bonin et al. 2007; Mosquera-Losada et al. 2009; Vermaat et al. 2009). Apart from these functions, these agroforestry practices provide profitable sources, such as timber and seasonal fruits (Mosquera-Losada et al. 2009). Nevertheless, FAO (The Food and Agriculture Organization of the United Nations) sorted woods forming riparian strips and line forests (hedgerows, shelterbelts, windbreaks) under the umbrella of so-called "trees outside the forests" (TOF) (de Foresta et al. 2013). And this could cause confusion as it mixed together different types of ecosystems.

Apart from rich variety of riparian buffer strips functions, windbreaks are primarily aimed to reduce losses caused by wind to agricultural crops (den Herder et al., 2015). The first mention about the existence of windbreaks in the Europe was found in the "*Commentarii de Bello Gallico*" (Commentaries on the Gallic War) written by Julius Caesar. He lived between 100 and 44 BC. There is written that Galls those are living between the rivers Maas and Scheldt is managing some forest belts (Trnka 2003). These forest belts were obstacle for Caesar´s army progress (Šanovec 1948). Other Galls that lived on the shores in Normandy and Brittany (French administrative region) planted row of trees around their fields to protect them against strong winds from the sea (Trnka 2003).

The distance between various parallel tree lines should be 10 meters at minimum. Windbreaks could be also applied in the variety of livestock systems to reduce heath stress, additional fodder production etc (den Herder et al., 2015). Windbreaks are distributed in many countries of the world. In Europe, there are well documented trees that formed windbreaks in several countries, e.g. cypresses (*Cupressus sempervirens* L.) in the Aegean islands and Crete. Some windbreaks like that ones from the Gallic ages are found on the shores of Belgium, Netherlands, Denmark, England, Scotland and Ireland. Other windbreaks can be seen for e.g. in the Switzerland or in the Russian Federation (Podhrázská et al. 2008). Windbreaks were also researched in Hungary. These documented windbreaks were 3-6 rows wide afforested belts of trees and/or hedgerows, protecting against wind, snow or sand blow. And it may serve as ecological corridors (Mosquera-Losada et al. 2009).

Historically, the first windbreaks were planted in the territory of nowadays Czech Republic around the 1750, primarily in the area around the river Elbe to protect the sandy soils. Other windbreaks were planted in the area around the river Ohře and in the South Moravian region (Podhrázská et al. 2008).

However, the most of current windbreaks in the Czech Republic was planted in the 1950s on the 1,754 ha, and about nearly 67% in the south Moravian region. However, the most of these windbreaks were not further managed for long time and thus most of them is currently in the bad condition, target woods are dying. (Šanovec 1948; Podhrázská et al. 2008). Target woods were oaks (*Quercus* spp.), eastern black walnut (*Juglans nigra*), and Norway maple (*Acer platanoides*). Other trees in mixture were ashes (*Fraxinus excelsior*), European white elms (*Ulmu slaevis*), linden (*Tilia cordata*), hornbeam (*Carpinus betulus*), wild cherry (*Prunus avium*), and poplars *(Poppulus* spp.). Apart from trees, also some shrubs were planted to enhance the windbreaks functionality, mainly common dogwood (*Cornus sanguinea*), also European privet (*Ligutrum vulgare*), European fly honeysuckle (*Lonicera xylosteum*), European spindle (*Euonymus europaeus*), guelder-rose (*Viburnum opulus*), elder (*Sambucus nigra*), black mulberry (*Morus nigra*), Siberian peashrub (*Caragana arborescens*), bladder-senna (*Colutea arborescens*) and in some parts of south Moravian region also lilac (*Syringa vulgaris*) Reidl 1955).

Since the 1990s, these windbreaks fell under the management of LCR, s.p. (State forest service of Czech Republic.) as it were later assigned to forest land (Podhrázská et al. 2008). After many years that windbreaks was not managed, LCR, s.p. started with the regeneration of windbreaks in the South Moravian region the years between 2007 and 2013. In these years was renewed sixty hectares of dysfunctional windbreaks on the thirty-five kilometres (SILVARIUM.CZ 2018). Next, LCR, s.p. decided to renew about 300 ha of windbreaks in the South Moravian region in 2016 (CESKATELEVIZE.CZ 2016). The further regeneration of other dysfunctional windbreaks in the South Moravian region is planned for this year. The plans are to renew other windbreaks on the 15.7 ha and to plant new windbreaks on the 11 ha of agricultural land. Both, the renewed and newly planted windbreaks will consist variety of woods originated in the Czech Republic in the tree and shrub layer. Tree layer will be dominated by sessile oak (*Quecuspetraea*), further on by pendunculate oak (*Quercus robur*), wild cherry (*Prunus avium*), Norway

maple (*Acer platanoides*), linden (*Tilia cordata*), hornbeam (*Carpinus betulus*), field maple (*Acer campestre*), wild service tree (*Sorbus torminalis*), large-leaved linden (*Tilia platyphyllos*), European wild pear (*Pyrus pyraster*), and European crab apple (*Malus sylvesris*).The shrub layer will be composed by common dogwood (*Cornus sanguinea*), common hazel (*Corylus avellana*), European privet (*Ligutrum vulgare*), woodland hawthorn (*Crataegus laevigata*), common hawthorn (*Crataegus monogyna*), European fly honeysuckle (*Lonicera xylosteum*), Cornelian cherry dogwood (*Cornus mas*), guelder-rose (*Viburnum opulus*), buckthorn (*Rhamnus cathartica*) (SILVARIUM.CZ 2018). Actually, LCR, s.p. manage around 1,500 ha of windbreaks (CESKATELEVIZE.CZ 2016).

Shelterbelts represent all the neighbouring cultivated area, where the shelterbelts do not exceed 10% of the agricultural area. The importance of shelterbelts lies in the enhanced spatial heterogeneity and soil conservation (den Herder et al. 2015). For eq., the area containing shelterbelts was measured in Hungary, where the landscape elements with shelterbelts were spread at around 16,415 ha in 2001 (Takáczs & Frank 2008).

Hedgerows consists of trees or thorny species of shrubs that are managed (cut and shaped) to appear as "walls" to separate agricultural fields from grasslands, land parcels among various owners (Herzog, 2000). Major types of hedgerows are still present in Brittany (*bocages*), Normandy, Ireland, the Knicks and Walhecken in Germany (Takács and Frank 2008). It was found out that most (71%) of the historical hedgerows (called *plužin*a) from the study areas disappeared between 1950 and 2005 in the Czech Republic during collectivization. Decline of these hedgerows was caused by the field enlargements with the connection to the progressing intensification of agricultural productions (Sklenicka et al. 2009). However, *Plužina* was more than just a hedgerow. It was a part of the landscape that could be agriculturally utilised and belongs to the village settlement. It was collective name for all the fields, grasslands, and pastures interconnected to the network of routes (Low and Míchal 2003).

In addition to line belts, tree formations along roadways or railways can be included. As it splits them from agricultural land and protect agriculture lands and artificial paths from strong wind and blown snow (Takács and Frank 2008).

2.4.2 Within-field agroforestry

Trees in this system are usually planted in single or grouped rows, within agricultural or horticultural fields and it is usually called alley cropping (Mosquera-Losada et al. 2009). The main features of this kind of agroforestry practice are widely spaced trees inter-cropped with annual or perennial crops (Eichhorn et al., 2006). The minimum is that tree height cannot exceed the width of alley (den Herder et al., 2015). This system is determined by its agricultural component that is regularly harvested every year or every few years for energy crops. To reduce harvesting losses, the trees are distributed broadly across the land to promote the ease of machinery usage. The further enhancement is made by the tree rows or surrounding plots (Mosquera-Losada et al. 2005). This system was on the rise in France in the 18th century, where poplars were intercropped with cereals (eq. maize). Nowadays, it covers about 6,000 ha in alluvial regions (Eichhorn et al., 2006). Other examples of alley cropping are in north-eastern Germany (sample plot) and in Hungary. In north-eastern Germany, there were planted poplars and black locust (*Robinia pseudoacacia*) as a short rotation coppice and intercropped with winter wheat (den Herder et al. 2015). Further on, there is another example of alley cropping from south-eastern Spain, cereal-*Atriplex* alley cropping, saltbushes planted in such rows that copy the broad contour lines. The benefits of this system were in situ protein supplement to straw/stubble and the soil protection for heavy autumn rainfalls (Correal et al. 1994).

It is not known how many of these silvoarable practices remained in the Czech Republic. The same is valid for hedgerows and other tree-formations, except the windbreaks (Zelba 2016).

2.5 Agroforestry practices for livestock systems

This group focused on integration of agroforestry with livestock production (silvopastoral systems). Under this group were identified practices such as forest and woodland grazing, open forests or tree plantation with wild or domestic animals (den Herder et al. 2015).

Silvopastoral systems offer alternative to common intensive livestock production in the battle with emissions mitigation and store carbon (Eve et al. 2014). Apart from

climatological aspects, it also may enhance animal welfare. It was proved for eq. woodland hens in the UK (Burgess et al. 2014). Agroforestry with animals and trees were often defined as "silvopastoral" systems, these systems cover the wood pastures and reindeer systems and it was included in the chapter 2.3.

2.6 Other Agroforestry practices

The last group is coined to other agroforestry practices that are considered as common agroforestry practice, others are balancing on the edge of the agroforestry scope and some of them are not considered as agroforestry practices at all (eq. wildcrafting). There belong practices such as *forest grazing*, *grazed heathlands*, *aqua culture with trees*, *apiculture with trees*, *home gardens*, and *forest farming* (den Herder et al. 2015).

Forest grazing practices is still practiced in some countries in Europe. For eq. it was estimated there are about 104 grazed woodlots that cover approximately 30,774 ha over England, Scotland and Wales in the UK. Most of the forests were regarded to be semi-natural, only 6,000 ha were tree plantations with Sitka spruce and other species. (Armstrong et al. 2003).

Grazed heathlands covered about 1,487,000 ha in the UK in 2003 (Howard et al., 2003). Grazed heathlands are classified as areas with 25% coverage of plant species from *Ericaceae* (heather) family, such as common heather (*Calluna vulgaris*). This perennial shrub is common for areas of North-West European upland heath (Thompson et al. 1995). Many of these areas are grazed by sheep (den Herder et al. 2015).

Aquaculture was defined by the FAO as "the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants" (FAO 2015). Aquaculture with trees is an enhanced system of regular aquaculture with the benefits from trees, specific trees and shrubs are chosen and planted on the banks of ponds to support fish "forage" (Nair 1993).

Apiculture and trees is traditional and long-term practice. This combination offers annual honey products (e.g. honey, bee wax) and it may substitute the landowner's income from long-term forest management (Hill & Webster 1995). This practice is frequently combined with Streuobst (Herzog 1998).

Home gardens cover myriad of species, both trees and agricultural crops. Apart from single story systems, home gardens are usually multiple storied systems with different species of trees, shrubs and crops. There are typically found nearby the house or farm. For many people are essential source of food and income. These practices contribute to the food security and livelihood on regional and on global scale (den Herder et al. 2015). There are some new ongoing projects that can be considered as home gardens, too (Food Forestry Netherlands 2018).

Forest farming is the intentional or purposeful change of forested lands to make special products, often food or medicinal products (Hill &Buck, 2000). At the other hand, wildcrafting is seasonal harvesting wild plants from their natural habitat, also for food or medicinal use. Wildcrafting or harvesting of these goods in the nature, is usually uncontrolled, thus it seems to be unsustainable and reduces overall profitability. Mushrooms, medicinal plants and berries are the most popular non-forest goods. However, their harvesting is not certainly regulated and it may result in crop damage (MCPFE 2003). However, wildcrafting is not considered as agroforestry practice.

2.7 Mapping Agroforestry

Mapping and inventorying the extension of agroforestry is essential step for further development of these land-use production systems. First inventory in the fields of agroforestry was primarily targeted at developing countries of tropics and subtropics and was undertaken by ICRAF between 1982 and 1987(Nair 1987). The World Agroforestry Centre is the world´s largest repository of agroforestry science and information (ICRAF 2018). Nevertheless, the first attempt to quantify the extent of agroforestry at the global level was study called “Trees on Farm: Analysis of Global Extent and Geographical Patterns of Agroforestry”. Among other results, they found out that approximately 46% of all land that fall under agriculture land use had in minimum 10% tree cover (Zomer et al. 2009). This study was later revisited and updated. One of the main results was that Agroforestry, if defined by tree cover of greater than 10% on agricultural land, is widespread; found on more that 43% of all agricultural land area globally; and linked to 30% of rural populations (Zomer et al. 2014).

One of the first articles that contributed to this problematic for Europe was "Modelling the potential distribution of agroforestry systems in Europe using GIS" and was published de Filippi et al. (2004). This study was based on the five typical tree species of European silvoarable systems: *Pinus pinea*, *Juglans* spp. (hybrids), *Populus* spp. (hybrids), *Quercus ilex* and *Prunus avium*. The result showed that approximately 53% of the arable land in Europe was found to fit for minimally one of the investigated tree species. Reisner et al. (2007) tried to estimate silvoarable systems of whole Europe and found out that they cover approximately 65,200,000 ha.

Within AGFORWARD project, den Herder et al. (2015) tried to stratify and quantify the main agroforestry practices in Europe based on the available literature sources. They found out that current area of agroforestry practices in Europe is at minimum 52 million ha, without the reindeer husbandry system is estimated at minimum 10.6 million ha (Table 5). Nevertheless, this estimate of the total agroforestry extent in Europe was not complete. They found out a missing data from some countries, eq. estimates of wood pastures from countries like Romania, Poland and Bulgaria. The other problem was with the various time frames and data in the publication den Herder et al. (2015)

Table 5. Preliminary stratification and quantification of key agroforestry practices in Europe.

System	**Country**	**Agroforestry practice**	**Extent (ha)**	**Arable/Livestock**
Mediterranean	Spain	*Dehesa*	3,606,151	Both
oak tree	Portugal	*Montado*	1,059,000	Both
agroforestry	Greece	Grazed woodlands and oak and other agroforestry on agricultural land	1,895,583	Both
	Spain and Portugal	Pyrenean oak	122,000	Livestock
	Italy	Grazed oak woodlands	279,263	Livestock
	Subtotal		6,961,997	

Source: den Herder et al. (2015)

Table 5. Preliminary stratification and quantification of key agroforestry practices in Europe, continued.

System	Country	Agroforestry practice	Extent (ha)	Arable/Livestock
Other wood pastures and meadows	Italy	*Larix decidua*	102,319	Livestock
	Sweden	*Lövängar, hagmarker*	100,000	Livestock
	UK, Germany, Austria, Switzerland, Hungary, Finland	Other parklands, woodland, wood-pasture, *Hudewald*, *Haka* and metsälaidun	200,320	Livestock
	Subtotal		402,639	
Reindeer husbandry	Finland, Sweden, Norway	Reindeer husbandry	41,400,000	Livestock
Hedges and scattered trees	France and parts of UK and Belgium	Hedges and scattered trees	472,074	Both
Agroforestry with fruit trees	Germany, Switzerland, Austria, Romania, Croatia, Czech Rep, France, UK, Denmark, Italy, Greece, Poland, Portugal	Mainly *Streuobst*	1,226,867	Both

Source: den Herder et al. (2015)

Table 5. Preliminary stratification and quantification of key agroforestry practices in Europe, continued.

System	Country	Agroforestry practice	Extent (ha)	Arable/Livestock
AF with olives	Portugal, Greece, France, Italy, Spain	Olives groves for olive oil and table olives	538,865	Arable
AF with pine-trees	Italy and Portugal	*Pinheiro manso*	535,842	Livestock
AF with vines	Italy, Spain, and Portugal	*Piantata* (Italy, Sicily)	275,635	Arable
AF with chestnuts	Portugal, France, Italy, Greece, Hungary, Romania, Slovakia, Slovenia, Spain and Switzerland	*Souto* (Portugal)	111,083	Both
AF with carob trees	Italy, Portugal, Spain, Greece		92,200	Both
	Sub-total		2,780,492	
Shelterbelts	Hungary		16,415	Both
Alley cropping	France		6,300	Arable
Trees with livestock	Netherlands		3,000	Livestock
Total			52,042,917	

Source: den Herder et al. (2015). Total extent of agroforestry practices without Reindeer husbandry is much lower, only 10,642,917 ha.

Afterwards, den Herder et al. (2017) tried to stratify and quantify agroforestry in the European Union with data obtained from LUCAS (Land Use and Cover Frame Area Survey). These data were later processed in the geospatial software called ArcGIS. According to den Herder et al. (2017), the total extent of agroforestry in European Union is approximately 15.4 million ha (Figure 4). It is an equivalent to 3.6% of the EU total area or 8.8% of the utilized agriculture area. According to this study, agroforestry in the Czech Republic covered about 45,800 ha. It is more than it was estimated in the previous study, where about 9,200 ha were identified as agroforestry (den Herder et al. 2015), and more than estimated Zelba (2016), 3,071 ha. The largest extent of agroforestry practices in EU in the absolute numbers have Spain (5.6 million ha), Greece (1.6 million ha), France (1.6 million ha), Italy (1.4 million ha), Portugal (1.2 million ha), Romania (888,200 ha) and Bulgaria (869,900 ha) (den Herder et al. 2017).

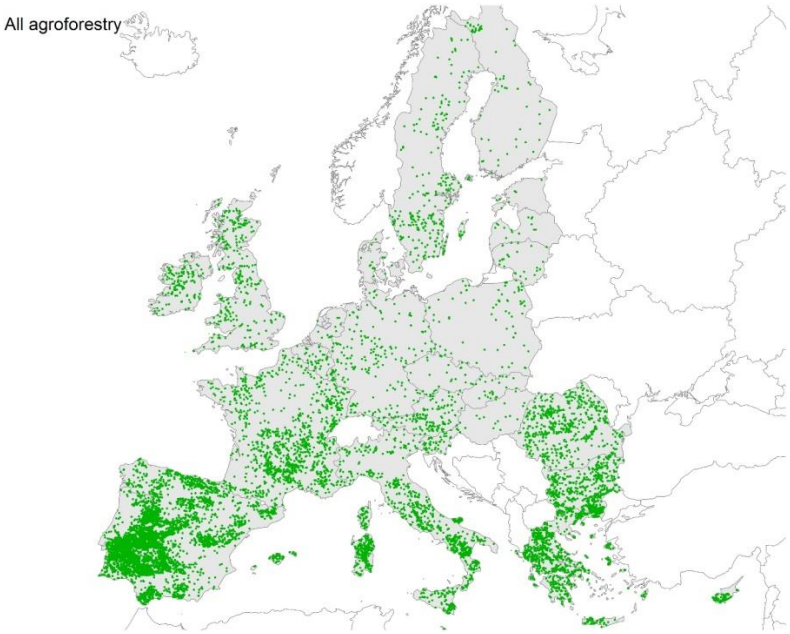

Figure 4. Total extent of agroforestry in the EU member states, taken from den Herder et al. (2017).

Arable agroforestry is practiced on approximately only 358,000 ha (Figure 5), it is an equivalent to about 0.1% of the EU area and 0.39% of utilized arable lands. The largest extent of arable agroforestry was found in Spain (117.000 ha), Italy (106.000 ha) and Portugal (76,500 ha) (den Herder et al. 2017).

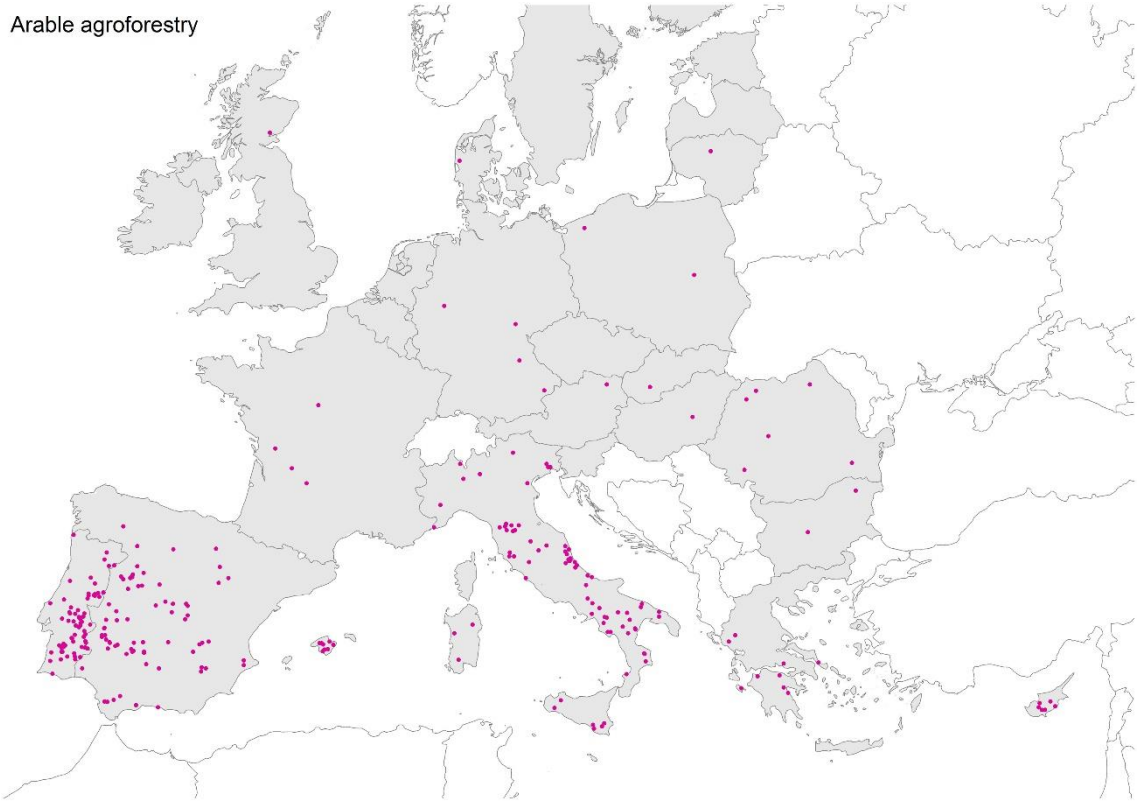

Figure 5. Extent of arable agroforestry in the EU member states, taken from den Herder et al. (2017).

Livestock agroforestry is practiced on approximately 15.1 million ha (Figure 6), it is an equivalent to about 3.5% of the EU area. It is further on equivalent of 15% of the grassland in EU and 35% of the grazed land. The largest extent of this kind of agroforestry was found in the Mediterranean member states, such as Spain (5.5 million ha), Greece (1.6 million), France (1.6 million ha), Italy (1.3 million ha) and Portugal (1.1 million ha) (den Herder et al. 2017).

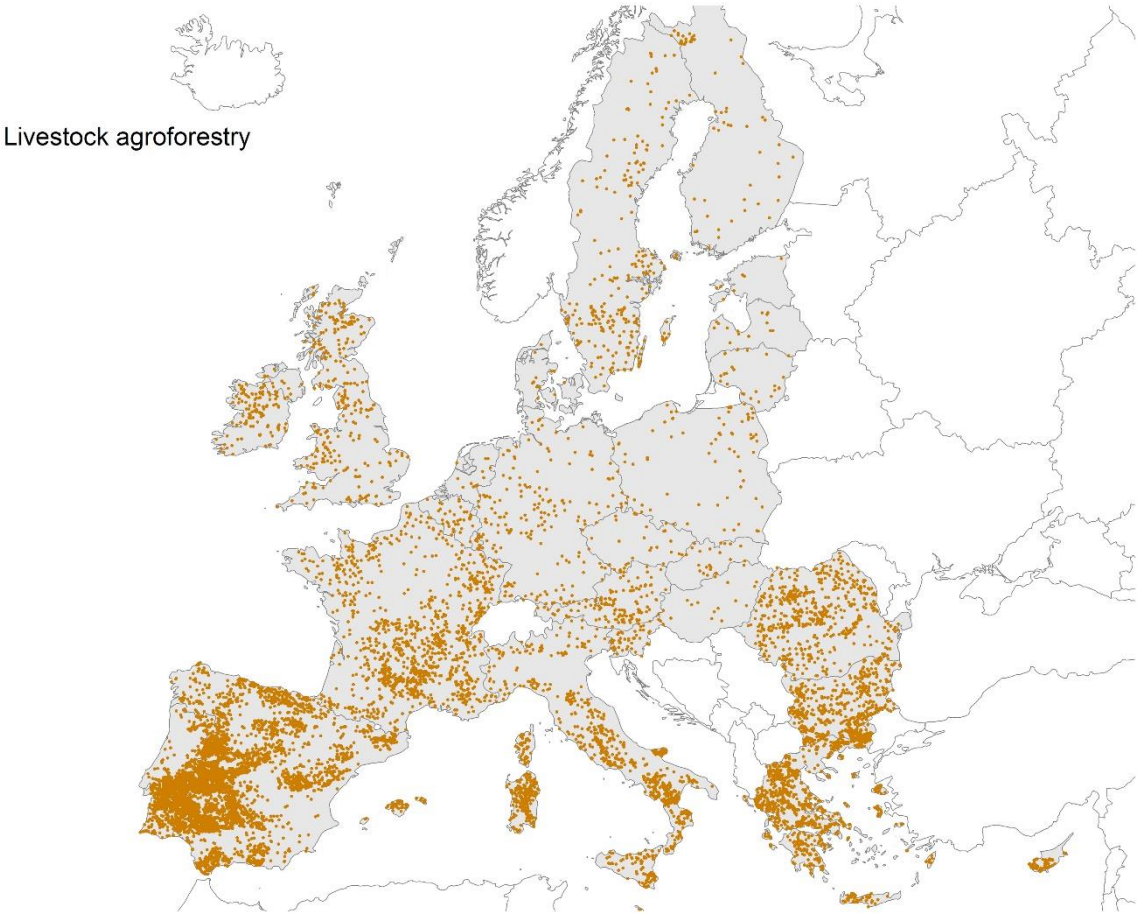

Figure 6. Livestock agroforestry extent in the EU member states, taken from den Herder et al. (2017).

High value tree agroforestry was found on about 1.1 million ha (Figure 7), it is an equivalent to approximately 0.2% of the EU area. 21% is intercropped and 79% is grazed. The largest extent of this kind of agroforestry was found in Spain (260,000 ha), Italy (202,200 ha) and Portugal (154,200 ha) (den Herder et al. 2017).

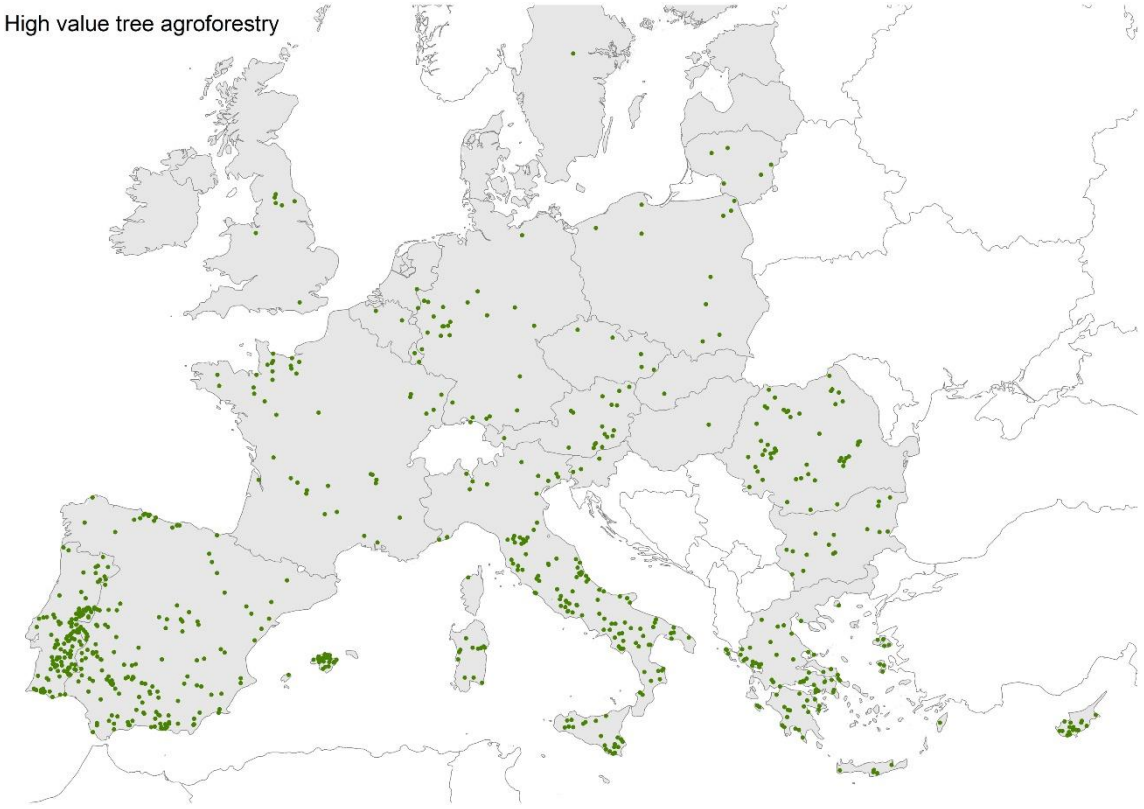

Figure 7. High value tree agroforestry the EU member states, taken from den Herder et al. (2017).

2.8 LUCAS

LUCAS is Land Use and Cover Frame Area Survey that provides harmonised and comparable statistics on land use and land cover across the whole of the EU's territory. It was at the early stage aimed to offer early crop estimates for the European Commission in the 2001. Further on, in 2006, the sampling methodology was modified to cover up various landscapes of EU - land cover, land use and landscape survey, with the three-year intervals. The latest survey was done in 2012 for all the EU-27 Member States. LUCAS offers multiple datasets with precise geographical coordinates of the land use and land cover (Eurostat 2018).

This survey is carried by the EUROSTAT every three years since 2006 to detect and identify any changes in land use and land cover in the European Union. LUCAS surveys are performed in situ. All the observations are made and recorded in the terrain all over the EU by surveyors. The surveyors follow the points with their starting list. The starting list for the LUCAS survey design is the LUCAS 2x2 km^2 grid (Figure 8).

Surveyors are responsible for the right identification of land cover and land use, irrigation management and structural elements in the landscape. Measured points vary between all the possible land cover types (transport networks, built up areas, forest, grassland, cropland, etc.). Apart from these activities, surveyors perform also soil sampling. To analyse the soil to assess environmental factors, update European soil models and measure the quantity of organic carbon in the soil, a 0,5 kg of topsoil is removed at one out of ten points. It is further on examined in a laboratory. The selected points are mapped and photographed sensitively to avoid large disturbance or to cause any damage. To easily cooperate and get access to the land and permissions for soil sampling, EUROSTAT contact all the affected landowners, agricultural business and authorities in charge (Eurostat 2018).

The newest published LUCAS survey is from 2015. It covered all the 28 EU countries, with the total number of observations that reached more than 270,000 points (5,515 points in the Czech Republic) in the terrain. The following LUCAS survey (LUCAS 2018) will start in Spring 2018 and its results will be published in 2019 (Eurostat 2018).

LUCAS offers three types of data sources from LUCAS surveys:

1. Micro-data for land cover, land use and environmental with detailed parameters that are linked to individual points
2. Points and landscape photos taken from all (four) the cardinal directions
3. Statistical tables with data linked to land cover and land use. All the estimates are based on weighted point data.

Data on land cover and land use statuses and changes are commonly used for (Eurostat 2018): Policy planning (spatial and territorial analysis), Nature protection, Forest and water management, Urban and transport planning, Agricultural policy, Prevention and mitigation of natural hazards, Soil protection and mapping, Monitoring climate change, Monitoring biodiversity, etc.

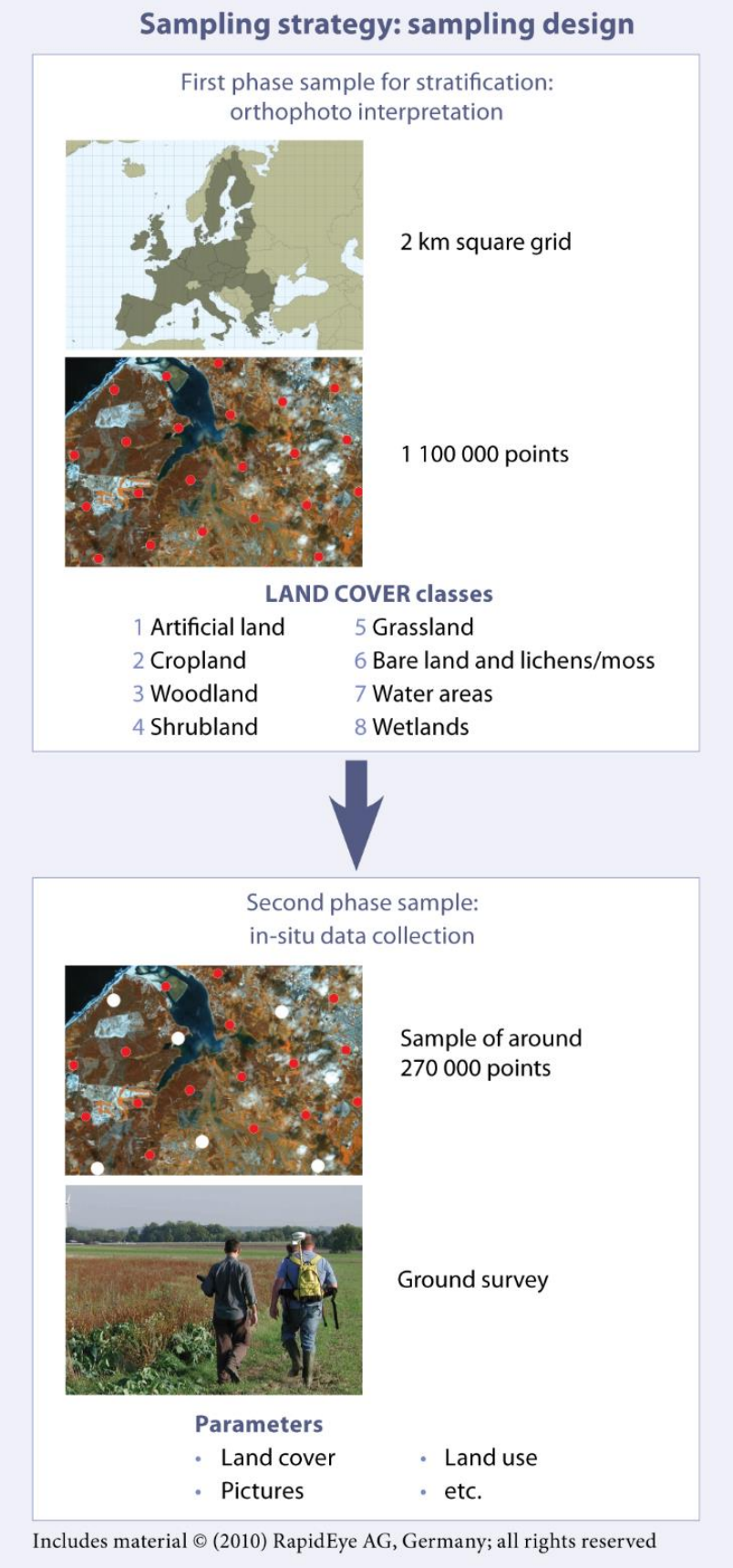

Figure 8. Schema for data collection, taken from the European Commission (2018).

3. Objectives

The main objective of this study was to estimate actual extent of agroforestry systems (AFS) in the Czech Republic.

The following specific objectives were defined:

i. To estimate and explore the current extent of AFS in the Czech Republic on the similar basis that was used by den Herder et al. (2017) using LUCAS;
ii. To find out and evaluate suitable methodology for inventory of those systems in the Czech Republic;
iii. To compare the actual results with the results from Zelba (2016) study;
iv. To make a map of agroforestry systems in the Czech Republic.

I set the following research questions based on the previously formulated objectives:

i. What types of AFS are found in the Czech Republic?
ii. Where are the AFS located in the Czech Republic?
iii. What agroforestry system is currently prevalent in the Czech Republic?
iv. What is the extension of various AFS in the Czech Republic?

4. Methods

4.1 Assessment of AFS using LUCAS

The current extent of AFS in the Czech Republic was estimated using LUCAS datasets. Only the points located inside Czech Republic were selected (Eurostat 2018). Same points with the same features as den Herder et al. (2017) used for the mapping of agroforestry for the whole EU. Additionally, the points from the 2015 and 2009 LUCAS surveys were added to the selections. Afterwards, various criteria were assigned to LUCAS variables (Table 6) to identify and select the three main agroforestry systems: arable agroforestry, livestock agroforestry and High value tree agroforestry, with their subsequent subcategories (Burgess et l., 2015; den Herder et al., 2015a,b):

1. Arable agroforestry where crops are integrated with trees.
2. Livestock agroforestry where livestock production is combined with trees.
3. High value tree agroforestry where prime role is taken by permanent woody crops, fruit orchards. Two subcategories were defined: a) grazed and b) intercropped.

It should be noted that these categories (systems) are not mutually exclusive. High value tree agroforestry can either be practiced as an arable system (category 1) or livestock system (category 2). Nevertheless, High value tree agroforestry was recognized as separate system as the prime objective for the owner are tree producing edible fruits or high value wood.

The points that fit the Arable agroforestry system were identified in the ArcMap by selection ("Select by Attributes") only those points where some wood vegetation was found from the primary land cover classes (LC1). Specifically, the following layers were selected: "permanent crops" (classes B71 to B84), "woodland" (classes C10-C33), and "shrubland with sparse tree cover" (class D10), and from this set of points were filtered only those points that consists also the secondary land cover of crops from classes B11 to B54, indicating that there were crops grown under fruit trees or forest trees.

Further on, the points that fit the Livestock agroforestry system were identified in the ArcMap by selection ("Select by Attributes") only those points where some wood vegetation was found with the marks of grazing. At first, identical primary land cover classes (LC1) were selected: "permanent crops" (B71 to B83), "woodland" (C10 to C33)

or “shrublands with sparse tree cover”. To this selection was added “grasslands with sparse tree cover” (E10). From this set of points, only those showing signs of grazing (“Land Management” column: 1 = “signs of grazing”; 2 = “no signs of grazing”) were recorded as livestock agroforestry.

To select the right points that fit the High value tree agroforestry system, the points that consisted “High value trees” were chosen. “High value trees” were defined as the trees that are harvested once or twice per year. Those trees were selected in the ArcMap by selection (“Select by Attributes”) from the land cover classifications (LC1) indicating points with high value trees. Selected points were: B71 for apple, B72 for pear, B73 for cherry, B74 for nuts, B75 for other fruit trees and berries and B82 for vineyards.

In the next step, from this set of points (“High value trees”) were sorted only those that either fit the subcategory grazed (Land management column) High value tree agroforestry or intercropped High value tree agroforestry (LC2, classes B11 to B54).

Table 6. Criteria used for identifying all agroforestry systems.

Land cover/ variable	**Code**	**LUCAS class**	**Arable AF**	**Live-stock AF**	**High value tree agroforestry**		**All AF**
					Inter-cropped	**Grazed**	
Cereals	B11	Common wheat	LC2		LC2		LC2
	B12	Durum wheat	LC2		LC2		LC2
	B13	Barley	LC2		LC2		LC2
	B14	Rye	LC2		LC2		LC2
	B15	Oats	LC2		LC2		LC2
	B16	Maize	LC2		LC2		LC2
	B18	Triticale	LC2		-		LC2

LC1 = primary land cover, LC2 = secondary land cover, dash (-): the variable was included in the analysis, but there were no observations where this land cover occurred in an agroforestry system, AF= agroforestry.

Table 6. Criteria used for identifying all agroforestry systems, continued.

Land cover/ variable	Code	LUCAS class	Arable AF	Live-stock AF	High value tree agroforestry		All AF
					Inter-cropped	Grazed	
	B19	Other cereals	LC2		LC2		LC2
Root crops	B21	Potatoes	LC2		LC2		LC2
	B22	Sugar beet	-		-		-
	B23	Other root crops	LC2		LC2		LC2
Non-permanent industrial crops	B31	Sunflower	LC2		LC2		LC2
	B32	Rape and turnip rape	-		-		-
	B33	Soya	-		-		-
	B37	Other non-permanent industrial crops	-		-		-
Dry pulses, vegetables and flowers	B41	Dry pulses	LC2		LC2		LC2
	B42	Tomatoes	LC2		LC2		LC2
	B43	Other fresh vegetables	LC2		LC2		LC2
	B44	Floricul-ture and ornament-tal plants	LC2		LC2		LC2
	B45	Straw-berries	LC2		LC2		LC2

LC1 = primary land cover, LC2 = secondary land cover, dash (-): the variable was included in the analysis, but there were no observations where this land cover occurred in an agroforestry system, AF= agroforestry.

Table 6. Criteria used for identifying all agroforestry systems, continued.

Land cover/ variable	Code	LUCAS class	Arable AF	Live-stock AF	High value tree agroforestry		All AF
					Inter-cropped	Grazed	
Fodder crops	B51	Clovers	LC2		LC2		LC2
	B52	Lucern	LC2		LC2		LC2
	B53	Other leguminous and mixtures for fodder	LC2		LC2		LC2
	B54	Mix of cereals	LC2		LC2		LC2
Permanent crops: fruit trees	B71	Apple	LC1	LC1	LC1	LC1	LC1
	B72	Pear	LC1	LC1	LC1	LC1	LC1
	B73	Cherry	LC1	LC1	LC1	LC1	LC1
	B74	Nut trees	LC1	LC1	LC1	LC1	LC1
	B75	Other fruit trees and berries	LC1	LC1	LC1	LC1	LC1
Other permanent crops	B82	Vine-yards	LC1/ LC2	LC1	LC1/ LC2	LC1	LC1/ LC2
Woodland	C10	Broad-leaved woodland	LC1	LC1			LC1

LC1 = primary land cover, LC2 = secondary land cover, dash (-): the variable was included in the analysis, but there were no observations where this land cover occurred in an agroforestry system, AF= agroforestry

Table 6. Criteria used for identifying all agroforestry systems, continued.

Land cover/ variable	Code	LUCAS class	Arable AF	Live-stock AF	High value tree agroforestry		All AF
					Inter-cropped	Grazed	
Woodland	C21	Spruce domi-nated woodland	-	LC1			LC1
	C22	Pine domi-nated woodland	LC1	LC1			LC1
	C23	Other coni-ferous woodland	LC1	LC1			LC1
	C31	Spruce domi-nated mixed woodland	-	LC1			LC1
	C32	Pine domi-nated mixed woodland	-	LC1			LC1
	C33	Other mixed woodland	-	LC1			LC1

LC1 = primary land cover, LC2 = secondary land cover, dash (-): the variable was included in the analysis, but there were no observations where this land cover occurred in an agroforestry system, AF= agroforestry

Table 6. Criteria used for identifying all agroforestry systems, continued.

Land cover/ variable	Code	LUCAS class	Arable AF	Live-stock AF	High value tree agroforestry		All AF
					Inter-cropped	Grazed	
Shrubland	D10	Shrubland with sparse tree cover	LC1	LC1			LC1
Grassland	E10	Grassland with sparse tree cover	-	LC1			LC1
Land manage-ment	1	Marks of grazing		Yes		Yes	Yes

LC1 = primary land cover, LC2 = secondary land cover, dash (-): the variable was included in the analysis, but there were no observations where this land cover occurred in an agroforestry system, AF= agroforestry

4.2 Mapping of AFS

For this work, student licence for the program ArcGIS (ArcMap 10.4.1) from the company Esri was obtained from Prague CULS and used to create map of AFS in the Czech Republic. The points were checked, all of them were united in one table and to each of them was assigned unique agroforestry group. The groups for the individual AFS were predefined in the previous sub-chapter (chapter 4.1).

4.3 Estimation of total extent of AFS in the Czech Republic

To estimate the total extent of agroforestry in the Czech Republic, den Herder et al. (2017) study was followed. To estimate the extent of agroforestry systems in ha, the number of points that was defined as to be agroforestry points were divided by the total number of LUCAS points for Czech Republic (5,515), and this value was multiplied by the total surface area of the Czech Republic (7,886,600 ha). Result was rounded to just

one decimal place. Individual agroforestry systems and their subcategories were estimated and calculated with the same method as the total extent of agroforestry in the Czech Republic.

To estimate the extent of Arable agroforestry group in the Czech Republic in ha, the number of points that was defined as to be Arable points were divided by the total number of LUCAS points for Czech Republic (5,515), and this value was multiplied by the total surface area of the Czech Republic (7,886,600 ha). Result was rounded to just one decimal place.

To estimate the extent of Livestock agroforestry system in the Czech Republic in ha, the number of points that was defined as to be Livestock agroforestry points were divided by the total number of LUCAS points for Czech Republic (5,515), and this value was multiplied by the total surface area of the Czech Republic (7,886,600 ha). However, all transient points with grazed High value tree agroforestry were considered as to be only grazed High value tree agroforestry points. Result was rounded to just one decimal place.

To estimate the extent of intercropped High value tree agroforestry system in the Czech Republic in ha, the number of points that was defined as to be intercropped High value tree agroforestry points were divided by the total number of LUCAS points for Czech Republic (5,515), and this value was multiplied by the total surface area of the Czech Republic (7,886,600 ha). Result was rounded to just one decimal place.

To estimate the grazed High value tree agroforestry system in the Czech Republic in ha, the number of points that was defined as to be grazed High value tree agroforestry points were divided by the total number of LUCAS points for Czech Republic (5,515), and this value was multiplied by the total surface area of the Czech Republic (7,886,600 ha). Result was rounded to just one decimal place.

4.4 Evaluation of the data in the field

Ten randomly selected points were chosen to check the real situation in the field (Table 7). Those points were visited, checked and photographed by the author of this thesis in between 3rd April to 5th April 2018, 21st April 2018, and 24th April 2018. Taken photo documentation was included in the Appendix. Afterwards, these points were

compared and those ones where the real situation met the described conditions were used for the map creation later.

Table 7. Randomly selected points.

Point ID	Land cover	Land use	Original survey date	Date of check	Survey land management	Area size (ha)
47542924	E10	U120	2015	03/04/2018	1	1
47862906	E10	U111	2015	03/04/2018	1	2
47942946	E10	U111	2009	04/04/2018	1	2
47542960	C10	U111	2009	04/04/2018	1	1
46922902	C10	U120	2009	05/04/2018	1	1
46642874	C10	U364	2009	21/04/2018	1	1
46222860	B71	U113	2009	21/04/2018	1	1
46162854	E10	U111	2012/2015	21/04/2018	1	2
48362944	E10	U111	2009	24/04/2018	1	1
48982916	B75	U111	2009	24/04/2018	1	3

Format: DD/MM/YYY, Area size is only estimation

Afterwards, selected LUCAS points were connected to the predefined AFS and the total extent of AFS in the Czech Republic were compared with findings of Zelba (2016).

4.5 Agroforestry systems on the parcels

After the successful selection of LUCAS points, these points were checked in the LPIS (Land Parcel Identification System) land registry and assigned to land blocks (or parcels) that fit their GPS coordinates. Currently, LPIS serve as freely accessible public register of the fields blocks (eagri.cz/public/app/lpisext/lpis/verejny/) that is commonly used for various purposes, including the administrative one (MZe, 2008). The points that were not found to be localized in between field blocks were localized in between units of cadastre of real estates that is managed by the State Administration of Land Surveying and Cadastre. Afterwards, the aerial photos cut-outs of positions of LUCAS points that

represented individual agroforestry systems with the layers of LPIS or in the combination of LPIS layer and layer with units of cadastre of real estates were taken (Appendix A).

5. Results

5.1 Assessment and mapping of AFS

25 points was found that fit at least one of the two agroforestry groups, High value tree agroforestry or Livestock agroforestry (Table 8). Under the group called High value tree agroforestry fell four points, more precisely to the subcategory a) grazed High value tree agroforestry. Under the group called Livestock agroforestry fell all the 25 points. However, four points of both groups fell in the both groups (48982916, 46222860, 46243060, and 47402986). To found out the distribution of individual agroforestry groups by points, was made map composition (Figure 9).

Table 8. Filtered points.

Point ID	**Land cover**	**Land use**	**Area size (ha)**	**Altitude (m.a.s.l.)**	**Agroforestry class**
47402986	B73	U111 – Agriculture	1	457	Both systems
46422852	C10	U111 – Agriculture	2	607	Livestock agroforestry
46582860	C10	U111 – Agriculture	3	727	Livestock agroforestry
46183074	C10	U120 - Forestry	3	193	Livestock agroforestry
47542924	E10	U120 - Forestry	3	478	Livestock agroforestry
46562844	E10	U111 – Agriculture	3	653	Livestock agroforestry
46162854	E10	U111 – Agriculture	2	768	Livestock agroforestry

U111 – Agriculture = excluding fallow land and kitchen gardens, m.a.s.l. = metres above sea level, Both systems = Livestock agroforestry and High value tree agroforestry

Table 8. Filtered points, continued.

Point ID	Land cover	Land use	Area size (ha)	Altitude (m.a.s.l.)	Agroforestry class
47862906	E10	U111 – Agriculture	2	238	Livestock agroforestry
46143076	E10	U111 – Agriculture	2	337	Livestock agroforestry
46243060	B72	U111 – Agriculture	1	281	Both systems
45222984	C10	U120 - Forestry	3	701	Livestock agroforestry
46223076	C10	U120 - Forestry	2	397	Livestock agroforestry
46362972	C22	U120 - Forestry	3	340	Livestock agroforestry
46422844	C23	U120 - Forestry	4	564	Livestock agroforestry
46402850	C33	U120 - Forestry	4	800	Livestock agroforestry
46222860	B71	U113 – Kitchen Garden	1	742	Both systems
48362944	E10	U – 111 Agriculture	1	246	Livestock agroforestry
47942946	E10	U – 111 Agriculture	2	444	Livestock agroforestry
46642874	C10	U364	1	456	Livestock agroforestry

U111 – Agriculture = excluding fallow land and kitchen gardens, m.a.s.l. = metres above sea level, U364 = nature reserve, Both systems = Livestock agroforestry and High value tree agroforestry

Table 8. Filtered points, continued.

Point ID	Land cover	Land use	Area size (ha)	Altitude (m.a.s.l.)	Agroforestry class
46922902	C10	U120	1	567	Livestock agroforestry
47542960	C10	U – 111 Agriculture	1	682	Livestock agroforestry
45363016	D10	U120	1	660	Livestock agroforestry
45962874	C21	U120	1	857	Livestock agroforestry
45102940	E10	U – 111 Agriculture	3	741	Livestock agroforestry
48982916	B75	U – 111 Agriculture	3	403	Both systems

U111 – Agriculture = excluding fallow land and kitchen gardens, m.a.s.l. = metres above sea level, Both systems = Livestock agroforestry and High value tree agroforestry

The highest situated agroforestry system was found on the LUCAS point ID 45962874, with the measured elevation 857 m.a.s.l. and was assigned to Livestock agroforestry. Nevertheless, the lowest situated agroforestry system was found on the LUCAS point ID 46183074, with the measured elevation 193 m.a.s.l. and was assigned to Livestock agroforestry. The average elevation of all the selected LUCAS points was 551.2 m.a.s.l.

Individual agroforestry systems were found in the seven different regions: Zlínský, Olomoucký, South Moravian, Czech Moravian highlands, South Bohemian, Ústecký, Pardubický, and Plzeňský. The size of area of individual LUCAS points ranged from 1 to 4 ha. However, it is not related to the real size of the land blocks that is showed in the subchapter 5.4.

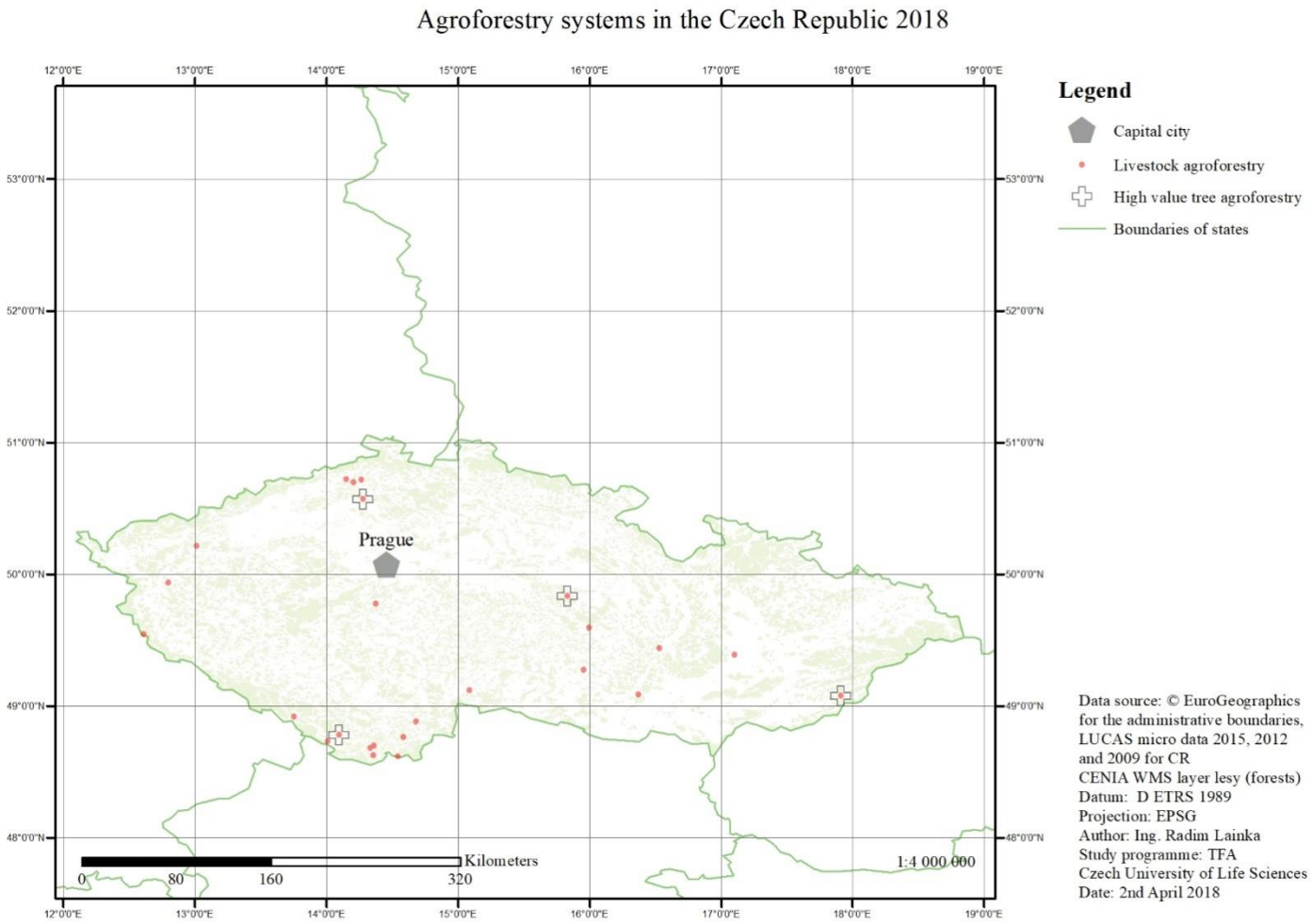

Figure 9. All agroforestry systems in the Czech Republic based on the LUCAS microdata (without subcategories).

5.2 Estimation of total extent of AFS in the Czech Republic

The most common agroforestry practice seems to be Livestock agroforestry that covers 30,030.6 ha, followed by grazed High value tree agroforestry covers 5,720.1 ha. No single point was found out to be considered as arable agroforestry or intercropped High value tree agroforestry. Thus, these agroforestry systems were not calculated. The total extent of agroforestry systems was calculated to be 35,750.7 ha.

5.3 Evaluation of the data in the field

All randomly selected points were validated as accurate in comparison to provided data from the previous LUCAS surveys (Table 9). The photo documentation made in the terrain was added to the Appendix.

Table 9. Results of randomly selected plots.

Point ID	Date of check	Note
47542924	3rd April 2018	intensive pasture, Red deer
47862906	3rd April 2018	goats, sheep and hens
47942946	4th April 2018	empty pasture
47542960	4th April 2018	extensive pasture, hazelnut shrubs
46922902	5th April 2018	empty pasture
46642874	21st April 2018	wetland with sparse trees (willows)
46222860	21st April 2018	orchard, nearby horses
46162854	21st April 2018	pasture with cows, line of silver birches
48362944	24th April 2018	empty pasture
48982916	24th April 2018	empty pasture with fruit trees and shrubs

(-) no further details

5.4 Agroforestry systems on the parcels

All land blocks with predefined agroforestry systems based on the various criteria applied to LUCAS points were found and collected to the table below (Table 10).

Table 10. Agroforestry systems as LUCAS point IDs assigned to land parcels.

Point ID	LPIS area (ha)	Parcel No.	Land use	Additional information
47402986	6.43	6305/9	permanent grassland	conventional management
46422852	0.0455	141	other area	infertile soil
46582860	0.8256	50	permanent grassland	-
46183074	0.2386	164/2	permanent grassland	-
47542924	0.1303	2962/7	agricultural land	-
46562844	33.24	5603	permanent grassland	-
46162854	21.9128	555/2	permanent grassland	-
47862906	0.0999	962/1	agricultural land	protection zone of water source, second degree
46143076	14.02	1002/15	permanent grassland	-
46243060	0.6315	266/2	other area	other area
45222984	0.1414	854/1	other area	other communication
46223076	1.7506	1258/1	forest land	-
46362972	6.49	0704/3	permanent grassland	conventional management
46422844	23.6173	1519/4	forest land	-
46402850	0.6808	296	forest land	-
46222860	1.038	1302/1	orchard	-
48362944	2.1046	888	agricultural land	-
47942946	1.35	0306/2	permanent grassland	conventional management
46642874	2.0801	776/1	permanent grassland	National Nature Reserve Brouskův mlyn
46922902	41.05	9605/12	permanent grassland	conventional management
47542960	1.59	7202/22	permanent grassland	stable pasture
45363016	2.5434	1268	other area	other area
45962874	1.1935	157/1	permanent grassland	-
45102940	81.05	0301/1	permanent grassland	conventional management
48982916	0.2589	2732	permanent grassland	conventional management

LPIS area (ha) = it consists data from cadastre of real estate in some examples

Agroforestry systems in the upper table are represented as individual LUCAS points. Parcel No. 9605/12 is the largest parcel where Livestock agroforestry system (LUCAS point ID 46922902) was found and it is near the Kačlehy village, in the South Bohemia region. At the other hand, parcel No. 141 is the smallest parcel where Livestock agroforestry system (LUCAS point ID 46422852) was found an it is near the Rožmitál na Šumavě village. The specific of this parcel is that lies on the infertile soil.

Fifteen out of twenty-five parcels (60%) are permanent grasslands to which some of the agroforestry systems were assigned (parcels No.: 6305/9, 50, 164/2, 5603, 555/2, 1002/15, 0704/3, 0306/2, 776/1, 9605/12, 7202/22, 157/1, 0301/1, and 2732). Four parcels (16%) are other areas (parcels No.: 141, 266/2, 854/1, 1268). Three parcels are forest lands (parcels No.: 1258/1, 1519/4, and 296). Another three parcels are agricultural lands (parcels No.: 2962/7, 962/7, and 888). And one parcel (No.1302/1) is orchard, it correlates with assigned agroforestry systems (High value tree agroforestry and Livestock agroforestry). It is in the vicinity of Olšina village, nearby the Olšina pond.

At the other hand, there are two quite specific parcels, parcel No. 962/1 and parcel No. 7761/1 that differ from the other parcels. First parcel (No. 962/1) lies in the protection zone of water source (second degree) to which may be applied some restrictions of management. This parcel is near Němčice u Ivančic and it fell under the Livestock agroforestry. Concretely this parcel was visited, checked and photographed on the 3rd April 2018 by author. There was found goats, sheep and hens.

The second parcel (No. 776/1) is a part of state protected area, National Nature Reserve Brouskův mlyn. It is nearby the Peškův mlýn (village house), near Borovany village. Aerial photos of all the parcels and LUCAS points are included in the Appendix.

6. Discussion

This study estimated agroforestry systems cover of about 35,751 ha in the Czech Republic, which is equivalent to 0.45 % of its territorial area and 0.8% of the utilised agricultural area. This estimate is considerably smaller than the den Herder et al. (2017) estimate (45,800 ha) that was based on the same methodology. However, this result is considerably higher than by den Herder et al. (2015a; 2015b) which was based only on a literature review, suggested that agroforestry in the Czech Republic occupied around 9,200 ha only, significantly more (3,0711 ha) than found Zelba (2016). The higher estimate for the AFS in the Czech Republic using the LUCAS data than the literature review can be partially explained by the availability of the data. The LUCAS sampling grid (2x2 km^2) may be not so precise for the AFS estimations for smaller countries like the Czech Republic, as there are some areas with higher landscape heterogeneity that are accompanied with various traditional and modern agricultural practices (e.g. White Carpathians).

There is missing a legal definition of agroforestry or AFSs in the Czech legislation and thus there are no available data for the further processing, utilisation and data management. Further on, this thesis was only focused on a spatial analysis of simultaneous agroforestry. Thus, it does not cover sequential agroforestry (rotational) systems (eq. short rotation coppice), where the trees are grown in the different time than crops (Nair, 1993). Also, this thesis does not consider the forest farming practices, homegardens, buffer strips, windbreaks, hedgerows, up to shelterbelts. Those missing agroforestry practices in the total estimation of all AFS in the Czech Republic may cover another thousands ha in addition to the estimation found in this work.

There are various examples of AFS that were excluded from the estimation, mainly due to methodology limitations. First example that was omitted is a land parcel owned by Ing. Radim Kotrba, PhD in the Miskovice village, located in the eastern part of Central Bohemia Region (former district of Kutná Hora). Its area is about 1 ha and it was formerly only cherry orchard. However, nowadays you can find on the same land with trees (mainly cherry and a few conifers) also animals like for e.g. red deer (*Cervus elaphus*), guanacos (*Lama guanicoe*) and extensive breed of sheep's. These animals are kept there for meat production. These AFS could be included into the grazed agroforestry

with high tree value and to the livestock agroforestry. In addition to this agroforestry land, he is planning to convert another piece of his own land into agroforestry land (personally visited).

The second example of omitted AFS in the Czech Republic are land blocks located in the territory of Černčice (nearby Milešovka hill) owned and managed by Daniel Pitek. There you can found grazed grasslands with dispersed woods and orchards by sheep, horses and red deer. These grazed orchards could belong to the High value tree agroforestry and the Livestock agroforestry, too. Grazed grasslands with dispersed woods may belong to the Livestock agroforestry.

Other examples of AFS that were omitted are some land blocks located in the White Carpathians. Some relicts of traditional grazed orchards are found in Pitin, Starý Hrozenkov, Šanov etc.). Some more modern agroforestry system (silvopastoral or livestock agroforestry) could be seen in Štítná nad Vláří on the field blocks owned and managed by Javorník-CZ s.r.o. Another example of grazed orchards is from Brumov-Bylnice (personally visited), where are found some grazed orchards that could belong to the High value tree agroforestry and the Livestock agroforestry, too.

The last example is from Prague, territorial area of Sedlec (nearby Vltava river). It is renewed orchard that covers about 1.63 ha with plenty varieties of cherry trees that is eventually grazed by flock of sheep and goats (PRAHA-PRIRODA.CZ 2018). This could be considered as another missing piece of the High value tree agroforestry mosaic that seems to be distributed in the various places of the Czech Republic. This example could be also included

Although Zelba (2016) followed a different approach that lead to different results with different level of bias, one single point (LUCAS ID 48982916) that fit predefined AFS in the Czech Republic in this work was also identical with one Zelba´s (2016) point that fit his definition of AFS in the Czech Republic. This point fit AFS predefined in this work, Livestock agroforestry and High value tree agroforestry. The estimated extent of AFS in the Czech Republic slightly differs. Zelba (2016) estimated that in the Czech Republic is 3,071 ha of agroforestry. However, this work estimated that there is more agroforestry, 35,750.7 ha. Zelba (2016) also found that most of the 3,071 ha of AFS in the Czech Republic was concentrated in the South Moravian region according to his own

methodology. Although, I found out higher extend of the AFS in the Czech Republic, most of the AFS were not concentrated in one region (Figure 9).

Most of the AFS were concentrated in the higher elevations of submontane areas and highlands. Probably, the reason behind it is that these AFS are somehow connected to the traditional agriculture practices of their regions: South Bohemian, Zlínský, and Czech Moravian highlands. However, the rest of the points that were found in the lowlands maybe linked to the traditional agricultural practices, too. At the other hand, one of them (LUCAS point ID 46642874) was found on the edge of the National Nature Reserve Brouskův Mlýn. Probably, this Livestock agroforestry system could be linked to the nature conservation activities in this area, instead of traditional agricultural practice of this region.

Finally, the results of this work may be affected by the various types of errors. Although it was used the same methodology and datasets as den Herder et al. (2017), this work found less points that fit predefined groups of AFS in the Czech Republic than den Herder et al. (2017). There is also some uncertainty about selected points. Some points that were identified as AFS according to the LUCAS datasets taken from surveys from the years 2009, 2012 and 2015 may simple do not fit the current conditions as these datasets are not so recent. There can be various reasons. However, one justification may arise from a change of the ownership of the affected land blocks that may be followed by the change of the land use. Another one may be caused due to wrongly mapped points. In comparison, Zelba (2016) that combined his selection of LUCAS points with the actual Corine Land Cover 2012 dataset - layer of polygons of so called Complex cultivation category (2.4.2) that may or may not lower the bias results according to his definition of agroforestry.

The better results to estimate the extent of AFS in the Czech Republic more precisely may be reached in the future by a methodology that will be based on the clear data containing correctly defined AFS linked with the parcels, considering that agroforestry will be legally backed by a change in the current legislation.

7. Conclusions

This study has reviewed different approaches in the mapping of agroforestry systems in Europe and tried to follow one of them and applied it in the national scale of the Czech Republic. This study estimated the total extent of agroforestry systems in the Czech Republic to be 35,751 ha. Together, this study found twenty-five agroforestry localities that fit the predefined agroforestry systems. Twenty-one of them were assigned to the Livestock agroforestry. Four of them were identified as High value tree agroforestry systems (grazed orchards) and Livestock agroforestry.

Although, the results of this study showed some distribution of agroforestry systems in the Czech Republic, it does not even consider the other agroforestry systems that were not covered by in this study, e.g. windbreaks and short rotation coppices (as sequential system). On the other hand, there is way how European Union could support the new agroforestry systems on the base of the Rural Development Program. However, this is problematic in the Czech Republic, as there is no law that supports agroforestry at all. The new law was already proposed by the *Český spolek pro agrolesnictví* and it was sent to the Ministry of Agriculture of Czech Republic for further validation etc.

8. References

Andersen E, et al. 2003. Developing a high nature value indicator. Report for the European Environment Agency, Copenhagen.

Alavapati JRR, Nair PKR. 2001. Socioeconomics and institutional perspectives of agroforestry. In Palo M, Uusivuori J (eds.) World forests, society and environment: markets and policies. Kluwer, Dordrecht, The Netherlands.

Alavapati JRR, Mercer DE, Monatambault JR. 2004. Agroforestry systems and valuation methodologies. In: Alavapati JRR, Mercer E (eds.) Valuing agroforestry systems: methods and applications. Kluwer, Dordrecht, The Netherlands

Altieri MA and Nicholls CA. 2002. The simplification of traditional vineyard based agroforests in northwestern Portugal: some ecological implications. Agroforestry Systems 56: 185-191.

Anuário Vegetal (2006) Crop Production Yearbook. Ministério da Agricultura, do desenvolvimento Rural e das Pescas. Available from: http://www.gpp.pt/publicacoes.html: Accessed 2018-04-12.

Armstrong HM, Poulsom E, Connolly T and Pearce A (2003) A survey of cattle-grazed woodlands in Britain. Roslin: Forest Research. Available from http://www.forestry.gov.uk/pdf/cattle_report.pdf/$FILE/cattle_report.pdf: Accessed 2018-04-12.

Association for Temperate Agroforestry (AFTA). 1997. The status, opportunities and needs for agroforestry in the United States. AFTA, Columbia, MO.

Bergmeier E, Petermann J and Schröder E. 2010. Geobotanical survey of wood-pasture habitats in Europe: diversity, threats and conservation. Biodiversity Conservation 19: 2995-3014.

Burgess PJ, et al. 2015. AGFORWARD Project Periodic Report: January to December 2014. Cranfield University: AGFORWARD. 95 pp. Available at: http://www.agforward.eu/index.php/en/: Accessed 2018-02-15.

Bonnin M, Bruzsik A, Delbaere B, Lethier H, Richerd D, Rientjes S, Van Uden G, Terry A, 2007. The Pan-European Ecological Network: taking stock, Vol. 146, Belgium, Council of Europe Publishing, 114p. ISBN 978-92-871-6119-2.

Caballero R and Gil Á. 2009. Binding constraints in Castile-La Mancha, Spain's cereal-sheep system. Journal of Sustainable Agriculture 33(1): 3-27.

CañellasI,Roig S, Poblaciones MJ, Gea-Izquierdo G, Olea L. 2007. An approach to acorn production in Iberian dehesas. Agroforestry Systems 70(1):3-9.

Castro M. 2009. Silvopastoral systems in Portugal: Current status and future prospects. In: Rigueiro-Rodríguez A, McAdam J and Mosquera-Losada M. (eds.) Agroforestry in Europe. Springer Netherlands.

CESKATELEVIZE.CZ (2016) Na jižní Moravě vznikají nové větrolamy. Chrání půdu přederozí. Available from: http://www.ceskatelevize.cz/ct24/regiony/1718872-na-jizni-morave-vznikaji-nove-vetrolamy-chrani-pudu-pred-erozi: Accessed 2018-04-12.

Conedera M, Manetti MC, Giudici F and Amorini E. 2004. Distribution and economic potential of the Sweet chestnut (Castanea sativa Mill.) in Europe. Ecologia Mediterranea 30(2): 179-193.

Cooper T, et al. 2007. Final report for the study on HNV indicators for evaluation. Report prepared by the Institute for European Environmental Policy for DG Agriculture. 187pp.

Copernicus (2018) Copernicus Land Monitoring Services. Satellite-borne earth observation data, Available from: http://land.copernicus.eu/: Accessed 2018-04-12.

Correal E, Ríos S, Sotomayor JA, Robledo A. 1994. Explotacionesovino-cereal: sistemas alternatives basados en la utilización de arbustos forrajeros y leguminous asperennes. Main paper presented at the XVIII Jornadas SEOC on Producción ovina y caprina., Ed. Universidad de Castilla-La Mancha, Col. Estudios, 21. Albacete, 23–25 Sept 1993.

de Fillipi R, Reisner Y, Herzog F, Dupraz C, Gavaland A, Moreno G, and Pilbeam DJ. 2004. Modelling the potential distribution of agroforestry systems in Europe using GIS. EnviroInfo 2004, Geneva.

De Foresta H, Somarriba E, Temu A, Boulanger D, Feuilly H and Gauthier M. 2013. Towards the assessment of trees outside forests. Resources Assessment Working Paper 183. Rome: Food and Agriculture Organization of the United Nations. Available from: http://www.fao.org/docrep/017/aq071e/aq071e00.pdf: Accessed 2018-04-12.

den Herder M, Burgess PJ, Mosquera-Losada MR, Herzog F, Hartel T, Upson M, Viholainen I, Rosati A. 2015a. Preliminary stratification and quantification of agroforestry in Europe. Milestone Report 1.1 for EU FP7 AGFORWARD Research Project (613520). Available from: http://agforward.eu/index.php/en/preliminary-stratification-and-quantification-of-agroforestry-in-europe.html: Accessed 2018-04-12.

den Herder M, Moreno G, Mosquera-Losada MR, Palma JHN, Sidiropoulou A, Santiago Freijanes J, Crous-Duran J, Paulo J, Tomé M, Pantera A, Papanastasis V, Mantzanas K, Pachana P, Burgess PJ, 2015b. Current extent and trends of

agroforestry in the EU27. Deliverable Report 1.2 for EU FP7 Research Project: AGFORWARD 613520. 99 pp. Available at: http://agforward.eu/index.php/en/current-extent-and-trends-of-agroforestry-in-the-eu27.html: Accessed 2018-12-12.

den Herder M, Moreno G, Mosquera-Losada MR, Palma JHN, Sidiropoulou A, Santiago Freijanes JJ, Crous-Duran J, Paulo JA, Tomé M, Pantera A, Papanastasis VP, Mantzanas K, Pachana P, Papadopoulos A, Plieninger T, Paul J. Burgess PJ. 2017. Current extent and stratification of agroforestry in the European Union. Agriculture, Ecosystems & Environment 241: 121-132

Dupraz C. 1999. Fodder trees and shrubs in Mediterranean areas: browsing for the future? Grassland Science 4:145-158.

Eichhorn MP, et al. 2006. Silvoarable systems in Europe - Past, present and future prospects. Agroforestry Systems 67(1): 29-50.

European Commission, 2013. Regulation 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation 1698/2005.

European Commission (2018) Schema for data collection. Available from: http://ec.europa.eu/eurostat/statistics-explained/images/1/1b/LUCAS_%E2%80%94_schema_for_data_collection_exercise.png: Accessed 2018-04-19.

Eurostat (2012) LUCAS 2012, Land Use/Cover Area Frame Survey. Technical Reference document: C-3 Land Use and Land Cover Classification (revised). Available from: http://ec.europa.eu/eurostat/web/lucas/methodology: Accessed 2018-03-10.

Eurostat (2018) LUCAS Land Use and Land Cover Survey. Eurostat Statistics explained, Available from: http://ec.europa.eu/eurostat/statistics- explained/index.php/ LUCAS_-_Land_use_and_land_cover_survey: Accessed 2018-04-12.

Eve M, Pape D, Flugge M, Steele R, Man D, Riley-Gilbert M, Biggar. 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. USDA technical bulletin 1939.

FAO. 1995. Non-wood forest products for rural income and sustainable forestry. FAO, Rome.

FAO. 1997. Medicinal plants for forest conservation and healthcare. FAO, Rome.

FAO (2015) Global Aquaculture Production. Avaible at: http://www.fao.org/fishery/statistics/global-aquaculture-production/en: Accessed 2018-12-12.

Fernández FJ, Rodríguez A. 2000. (eds). Os cogumelos nos ecosistemas forestais galegos. Xerais, Vigo, Spain.

Forestry Commission (2001a) National Inventory of Woodland and Trees - England. Edinburgh: Forestry Commission. Available from http://www.forestry.gov.uk/pdf/niengland.pdf/$FILE/niengland.pdf: Accessed 2018-04-12.

Forestry Commission (2001b) National Inventory of Woodland and Trees - Scotland. Edinburgh: Forestry Commission. Available from http://www.forestry.gov.uk/pdf/niscotland.pdf/$FILE/niscotland.pdf: Accessed 2018-04-12.

Forestry Commission (2001c) National Inventory of Woodland and Trees - Wales. Edinburgh: Forestry Commission. http://www.forestry.gov.uk/pdf/niwales.pdf/$FILE/niwales.pdf: Accessed 2018-04-12.

Hartel T and Plieninger T. 2014. European wood-pastures in transition: a social-ecological approach. Routledge, London.

Herzog F. 1998. Streuobst: a traditional agroforestry system as a model for agroforestry development in temperate Europe. *AgroforestrySystems42*. p61-80. ITT

Herzog J. 2000. The Importance of perennial trees for the balance of northern European agricultural landscapes. Unasylva 200(51)”42-48.

Hill DB, and Buck LE. 2000. Forest Farming Practices. In: Garrett Gene HE (ed.). 2000. North American Agroforestry: An Integrated Science and Practice. USA.

Hill DB, and Webster TC. 1995. Apiculture and forestry (bees and trees). Agroforestry Systems, 29(3), 313-320.

Howard DC, Watkins JW, Clarke RT, Barnett CL and Stark GJ. 2003. Estimating the extent and change in Broad Habitats in Great Britain. Journal of Environmental Management 67: 219–227.

ICRAF (2018) About us. Available from: http://www.worldagroforestry.org/about: Accessed 2018-04-12: Accessed 2018-04-12.

Inventário Florestal Nacional. 2013. Inventário Florestal Nacional -National Forest Inventory. Instituto da Conservação da Natureza e das Florestas. Lisboa. Available from: www.icnf.pt/portal/florestas/ifn: Accessed 2018-03-10.

Jongman, R. H. G. and Kristianses, I., 2001. National and Regional Approaches for Ecological Networks in Europe, Strasbourg, Council of Europe Publishing, 86p. ISBN 92-871-4781-7.

Jongman, R. H. G. and Kamphorst, D., 2002. Ecological Corridors in Land Use Planning and Development Policies, Strasbourg, Council of Europe Publishing, 86p. ISBN 92-871-4936-4.

Kiritsakis AK 1998. Olive Oil from the Tree to the Table, 2nd edition. Food and Nutrition Press, Trubull, CT.

Krčmářová J and Jeleček L. 2016. Czech traditional agroforestry: historic accounts and current status. Agroforestry Systems. Dordrecht: Springer, 2016. DOI 10.1007/s10457-016-9985-0

Laird SA, Pierce AR. 2002. Promoting sustainable and ethical botanicals: strategies to improve commercial raw material sourcing. Rainforest Alliance, New York

Löw J and Míchal I. 2003. Krajinný ráz. Lesnická práce, s. r. o.

Lundgren B. 1982. Introduction [Editorial]. Agroforestry Systems 1:3-6.

MacDicken KG, Vegara NT. 1990. Agroforestry: Classification and Management. John Wiley & Sons, New York.

MCPFE (2003) State of Europe´s forests 2003. MCPFE, Vienna, Austria. Available from: http://www.unece.org/trade/timber/docs/sfm/europe-2003.pdf: Accessed 2018-04-12.

Ministerio de Agricultura, Alimentación y Medio Ambiente. 2008. Diagnóstico de las Dehesas IbéricasMediterráneas. Tomo I.

Ministerstvo zemědelství. 2008. Uživatelská dokumentacep LPIS- Veřejný Registr půdy. Praha.

Molnárová K, Šímová P, Kotaška J, Ešnerová J, Škvárová Š, 2008. Hedgerow-defined medieval field patterns in the Czech Republic: a case study of the dendrological and dendrochronological structure of hedgerows of varying ages in Northern Moravia. Journal of Landscape Studies 1: 145 – 158.

Moreno G and Pulido FJ. 2009. The functioning, management and persistence of dehesas. In: Rigueiro-Rodríguez, A., McAdam, J., Mosquera-Losado, M. (eds) Agroforestry in Europe (pp. 127-160). Springer Netherlands.

Moreno, G et al. 2017. Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem service. Agroforestry Systems (el1572-9680) DOI: 10.1007/s10457-017-0126-1.

Mosquera-Losada, M.R., McAdam, J., Romero-Franco, R., Santiago-Freijanes, J.J., Riguero-Rodríquez, A., 2009. Definitions and components of agroforestry practices in Europe. In: Rigueiro-Rodrigues A., McAdam J, Mosquera-Losada MR, Rigueiro-Rodrigues A. 2009. *Agroforestry in Europe: Current Status and Future Prospects.* New York: Springer, ISBN 9781402082719.

Mosquera-Losada MR, Moreno G, Pardini A, McAdam JH, Papanastasis V, Burgess PJ, Lamersdorf M, Castro FL, Rigueiro-Rodríguez A.2012. Past, present and future of agroforestry systems in Europe. In: Agroforestry-the future of global land use. Springer, Dordrecht, pp 285–312

Nair PKR. 1987. Agroforestry systems inventory. Agroforestry Systems 3:97-128. In Nair PKR. 1993. An Introduction to Agroforestry. Kluwer, The Netherlands.

Nair PKR. 1993. An Introduction to Agroforestry. Kluwer, The Netherlands. In Nair PKR and Garrity D (eds.), 2012. Agroforestry – The Future of Global Land Use. Dordrecht: Springer, 2012. ISBN 978-94-007-4675-6.

Nair PKR, Gordon AM and Mosquera-Losada, MR, 2008. Agroforestry. In: Jørgensen, SE and Fath (eds.), 2008. Encyclopedia of ecology, London: Elsevier.

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. Stuttgart, Germany: Springer Science+Business Media.

Oppermann R, Beaufoy G and Jones G. (eds.) 2012. High Nature Value Farming in Europe. Ubstadt-Weiher, Verlag Regionalkultur.

Osborne L, & Kovacic D. 1993.Riparian vegetated buffer strips in water-quality restoration and stream management. *FreshwaterBiology* p243-258.

Palma JHN, Graves AR, Burgess PJ and Herzog F. 2007. Integrating environmental and economic performance to assess modern silvoarable agroforestry in Europe. Ecological Economics 63: 759-767.

Papanastasis VP, Mantzanas K, Dini-Papanastasi O, and Ispikoudis I 2009. Traditional agroforestry systems and their evolution in Greece. In: Rigueiro-Rodríguez A, McAdam J, Mosquera-Losado M (eds.) Agroforestry in Europe. Springer Netherlands.

Paracchini ML, Terres, JM, Petersen JE and Hoogeveen Y. 2006. Background document on the methodology for mapping high nature value farmland in EU27. European Environment Agency, Copenhagen, 32 pp.

Pardini A. 2009. Agroforestry systems in Italy: Traditions towards modern Management. In: Rigueiro-Rodríguez A, McAdam J, Mosquera-Losado M (eds.) Agroforestry in Europe: Springer Science + Business Media B.V., Dordrecht, p. 255-267.

Plieninger T, Hartel T, Martin-López B, Beaufoy G, Bergmeier E, Kirby K, Montero M J, Moreno Gm Oteros-Rozas E, Van Uytvanck J. 2015. Wood-pastures of Europe: Geographic coverage, social-ecological values, conservation management, and policy implications. Biological Conservation 190: p70-79.

Podhrázská J, Novotný I, Rožnovký J, Hradil M, Toman F, Dufků J, Macků J, Krejci J, Pokladníková H, Středa T. 2008. Optimalizace funkcí větrolamů v zemědělské krajině: Metodika. Brno: Výzkumný ústav meliorací a ochrany půdy v.v.i. ISBN 978-80-904027-1-3.

Pointereau P, Paracchini ML, Terres JM, Jiguet F, Bas Y and Biala K 2007. Identification of High Nature Value farmland in France through statistical information and farm practice surveys. JRC Scientific and Technical Reports. European Commission Joint Research Centre, Institute for Environment and Sustainability. Luxembourg: Office for Official Publications of the European Communities, 76 pp.

PRAHA-PRIRODA.CZ (2018) Sedlecký sad s úvozovou cestou. Avaible from: http://www.praha-priroda.cz/ovocne-sady-a-aleje/sady-a-aleje-dle-katastru/sedlec/sedlecky-sad-s-uvozovou-cestou/: Accessed 2018-04-12.

Reisner Y, de Filippi R, Herzog F and Palma J. 2007. Target regions for silvoarable agroforestry in Europe. Ecological Engineering 29, p. 401-418.

Riedl O. 1955. Zkušenosti se zakládáním ochranných lesních pásů na jižní Moravě. Československá akademie zemědělských věd. Praha.

Schoeneberger M, Bentrup G, Gooijer H, Soolanayakanahally R, Sauer T, Brandle J, Zhou X and Current D. 2012. Branching out: Agroforestry as a climate change mitigation and adaptation tool for agriculture. Journal of Soil and Water Conservation 67(5): 128A-136A.

SILVARIUM.CZ (2018. Lesy ČR obnovují a zakládají větrolamy v Jihomoravském kraji (TZ LCŘ). Available from:<http://www.silvarium.cz/zpravy-z-oboru-lesnictvi-a-drevarstvi/lesy-cr-obnovuji-a-zakladaji-vetrolamy-v-jihomoravskem-kraji-tz-lcr>.

Sklenicka P, Molnarova K, Brabec E, Kumble P, Pittnerova B, Pixova K, and Salek M. 2009. Remnants of medieval field patterns in the Czech Republic: Analysis of driving forces behind their disappearance with special attention to the role of hedgerows. Elsevier. Agriculture, Ecosystems & Environment 129(4): 465-473.

Smith J. 2010. The history of temperate agroforestry. Organic Research Centre, Elm Farm, UK.

Stevenson AC and Harrison RJ. 1992. Ancient forests in Spain: a model for land-use and dry forest management in south-west Spain from 4000 BC to 1900 AD. Proc. Prehistoric Soc. 58: 227–247.

Schultz AM, Papanastasis V, Katelman T, Tsiouvaras C, Kandrelis S and Nastis A. 1987. Agroforestry in Greece. Working document. Laboratory of Range Science, Department of Range and Wildlife Science, Aristotle University of Thessaloniki. Thessaloniki, 101 pp.

Šanovec J. 1948. Větrolomy, nový způsob meliorace pozemků. Praha. Brázda.

Takács V, Frank N. 2008. The traditions, resources and potential forest growing and multipurpose shelterbelts in Hungary.

Thompson DBA, MacDonald AJ, Marsden JH and Galbraith CA. 1995. Upland heather moorland in Great Britain: a review of international importance, vegetation change and some objectives for nature conservation. Biological Conservation 71: 163-178.

Trnka P. 2003. Historie, současnost a perspektiva větrolamů. AgroMagazín, 4 (4):31-33.

Vermaat JE, Gilbert AJ, Hellmann. 2009. Riparian nitrogen retention along streams and rivers in intensively used catchments in NW Europe – technical note. Institute for Environmental Studies. Amsterdam, Netherlands.

Walter KS, Gillet JJ (eds.). 1998. IUCN Red List of Threatened Plants. World Conservation Monitoring Centre, IUCN, Cambridge.

Zelba O. 2016. Agroforestry in Czech Republic. [MSc. Thesis]. Czech University of Life Sciences Prague, Czech Republic.

Zomer RJ, Trabucco A, Coe R, Place F. 2009. Trees on Farm: Analysis of Global Extent and Geographical Patterns of Agroforestry. ICRAF Working Paper no. 89. Nairobi, Kenya: World Agroforestry Centre.

Zomer RJ, Trabucco A, Coe R, Place F, van Noordwijk M, Xu JC. 2014. Trees on farms: an update and reanalysis of agroforestry's global extent and socio-ecological 42 characteristics. Working Paper 179. Bogor, Indonesia: World Agroforestry Centre (ICRAF)